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AEDC-TR-68-91

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ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TESTS J4-1801-24 THROUGH 27)

D. E. Franklin and H. J. Counts, Jr.

ARO, Inc.

June 1968

LARGE ROCKET FACILITY

ARNOLD ENGINEERING DEVELOPMENT CENTER

AIR FORCE SYSTEMS COMMAND

ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

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FOREWORD

The work reported herein was sponsored by the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC) (I-E-J), under System 921E, Project 9194.

The results of the tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. Program direction was provided by NASA/MSFC; engineering liaison was provided by North American Rockwell Corporation, Rocketdyne Division, manufacturer of the J-2 rocket engine, and McDonnell Douglas Corporation, Douglas Aircraft Company, Missile and Space Systems Division, manufacturer of the S-IVB stage. The testing reported herein was conducted on January 16, 24, 30 and February 6, 1968, in Propulsion Engine Test Cell (J-4) of the Large Rocket Facility (LRF) under ARO Project No. KA1801. The manuscript was submitted for publication on March 27, 1968.

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ABSTRACT

Eleven firings of the Rocketdyne J-2 rocket engine were conducted during test periods J4-1801-24 through 27 on January 16, 24, and 30 and February 6, 1968, in Test Cell J-4 of the Large Rocket Facility. The firings were accomplished at pressure altitudes ranging from 85,000 to 109,000 ft at engine start to investigate (1) engine start transients for both S-IVB first burn and (2) 80-min orbital restart with the engine in a 230,000-lb_f-thrust configuration. Engine components were thermally conditioned to temperatures representative of an S-IVB first burn or 80-min orbital restart. The total accumulated firing duration for the four test periods was 188.43 sec. Engine operation appeared to be satisfactory.

CONTENTS

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I. ILLUSTRATIONS

NOMENCLATURE

A	Area, in.^{2}
ASI	Augmented spark igniter
ES	Engine start, designated as the time that the helium control and ignition phase solenoids are energized
GG	Gas generator
MOV	Main oxidizer valve
NPSH	Net positive suction head, ft
STDV	Start tank discharge valve
t_0	Defined as the time at which the opening signal is applied to the start tank discharge valve solenoid
VSC	Vibration safety counts, defined as engine vibration in excess of 150 g/rms in a 960- to 6000-Hz frequency range

SUBSCRIPTS

f	Force
m	Mass
t	Throat

SECTION I
INTRODUCTION

Testing of the Rocketdyne J-2 rocket engine using an S-IVB battleship stage has been in progress since July, 1966, at AEDC in support of J-2 engine application on the Saturn IB and Saturn V launch vehicles for the NASA Apollo Program. The 11 firings reported herein were conducted during test periods J4-1801-24 through 27 on January 16, 24, and 30 and February 6, 1968, respectively, in Propulsion Engine Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Large Rocket Facility (LRF). These firings were to investigate engine start transients for both S-IVB first burn and 80-min orbital restarts utilizing a 230,000-lb_f-thrust configuration engine. The firings were accomplished at pressure altitudes ranging from 85,000 to 109,000 ft (geometric pressure altitude, Z, Ref. 1) at engine start. Engine components were conditioned to temperatures predicted for an S-IVB first burn or 80-min restart. Data collected to accomplish the test objectives are presented herein. The results of the previous test period are presented in Ref. 2.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The test article was a J-2 rocket engine (Fig. 3) designed and developed by Rocketdyne Division of North American Rockwell Corporation. The engine uses liquid oxygen and liquid hydrogen as propellants and has a thrust rating of 230,000 lb_f at an oxidizer-to-fuel mixture ratio of 5.5. An S-IVB battleship stage was used to supply propellants to the engine. A schematic of the battleship stage is presented in Fig. 4.

Listings of major engine components and engine orifices for this test period are presented in Tables I and II, respectively (Appendix II). All engine modifications and component replacements performed since the previous test period are presented in Tables III and IV, respectively.

2.1.1 J-2 Rocket Engine

The J-2 rocket engine (Figs. 3 and 5, Ref. 3) features the following major components:

1. Thrust Chamber - The tubular-walled, bell-shaped thrust chamber consists of an 18.6-in.-diam combustion chamber (8.0 in. long from the injector mounting to the throat inlet) with a characteristic length (L*) of 24.6 in., a 170.4-in.^{2} throat area, and a divergent nozzle with an expansion ratio of 27.1. Thrust chamber length (from the injector flange to the nozzle exit) is 107 in. Cooling is accomplished by the circulation of engine fuel flow downward from the fuel manifold through 180 tubes and then upward through 360 tubes to the injector.

2. Thrust Chamber Injector - The injector is a concentric-orificed (concentric fuel orifices around the oxidizer post orifices), porous-faced injector. Fuel and oxidizer injector orifice areas are 25.0 and 16.0 in.^{2}, respectively. The porous material, forming the injector face, allows approximately 3.5 percent of total fuel flow to transpiration cool the face of the injector.

3. Augmented Spark Igniter - The augmented spark igniter unit is mounted on the thrust chamber injector and supplies the initial energy source to ignite propellants in the main combustion chamber. The augmented spark igniter chamber is an integral part of the thrust chamber injector. Fuel and oxidizer are ignited in the combustion area by two spark plugs.

4. Fuel Turbopump - The turbopump is composed of a two-stage turbine-stator assembly, an inducer, and a seven-stage axial-flow pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 38,215 ft (1248 psia) of liquid hydrogen at a flow rate of 8585 gpm for a rotor speed of 27,265 rpm.

5. Oxidizer Turbopump - The turbopump is composed of a two-stage turbine-stator assembly and a single-stage centrifugal pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 2170 ft (1107 psia) of liquid oxygen at a flow rate of 2965 gpm for a rotor speed of 8688 rpm.

6. Gas Generator - The gas generator consists of a combustion chamber containing two spark plugs, a pneumatically operated control valve containing oxidizer and fuel poppets, and an injector assembly. The oxidizer and fuel poppets provide a fuel lead to the gas generator combustion chamber. The high energy gases produced by the gas generator are directed to the fuel

turbine and then to the oxidizer turbine (through the turbine crossover duct) before being exhausted into the thrust chamber at an area ratio (A/A_t) of approximately 11.

7. Propellant Utilization Valve - The motor-driven propellant utilization valve is mounted on the oxidizer turbopump and bypasses liquid oxygen from the discharge to the inlet side of the pump to vary engine mixture ratio.

8. Propellant Bleed Valves - The pneumatically operated fuel and oxidizer bleed valves provide pressure relief for the boiloff of propellants trapped between the battleship stage prevalves and main propellant valves at engine shutdown.

9. Integral Hydrogen Start Tank and Helium Tank - The integral tanks consist of a 7258-in.^{3} sphere for hydrogen with a 1000-in.^{3} sphere for helium located within it. Pressurized gaseous hydrogen in the start tank provides the initial energy source for spinning the propellant turbopumps during engine start. The helium tank provides a helium pressure supply to the engine pneumatic control system.

10. Oxidizer Turbine Bypass Valve - The pneumatically actuated oxidizer turbine bypass valve provides control of the fuel turbine exhaust gases directed to the oxidizer turbine in order to control the oxidizer-to-fuel turbine spinup relationship. The fuel turbine exhaust gases which bypass the oxidizer turbine are discharged into the thrust chamber.

11. Main Oxidizer Valve - The main oxidizer valve is a pneumatically actuated, two-stage, butterfly-type valve located in the oxidizer high pressure duct between the turbopump and the main injector. The first-stage actuator positions the main oxidizer valve at the 14-deg position to obtain initial thrust chamber ignition; the second-stage actuator ramps the main oxidizer valve full open to accelerate the engine to main-stage operation.

12. Main Fuel Valve - The main fuel valve is a pneumatically actuated butterfly-type valve located in the fuel high pressure duct between the turbopump and the fuel manifold.

13. Pneumatic Control Package - The pneumatic control package controls all pneumatically operated engine valves and purges.

14. Electrical Control Assembly - The electrical control assembly provides the electrical logic required for proper sequencing of engine components during operation.

15. Primary and Auxiliary Flight Instrumentation Packages - The instrumentation packages contain sensors required to monitor critical engine parameters. The packages provide environmental control for the sensors.

2.1.2 S-IVB Battleship Stage

The S-IVB battleship stage is approximately 22 ft in diameter and 49 ft long and has a maximum propellant capacity of 46,000 lb of liquid hydrogen and 199,000 lb of liquid oxygen. The propellant tanks, fuel above oxidizer, are separated by a common bulkhead. Propellant prevalves, in the low pressure ducts (external to the tanks) interfacing the stage and the engine, retain propellant in the stage until being admitted into the engine to the main propellant valves and serve as emergency engine shutoff valves. Propellant recirculation pumps in both fuel and oxidizer tanks are utilized to circulate propellants through the low pressure ducts and turbopumps before engine start to stabilize hardware temperatures near normal operating levels and to prevent propellant temperature stratification. Vent and relief valve systems are provided for both propellant tanks.

Pressurization of the fuel and oxidizer tanks was accomplished by facility systems using hydrogen and helium, respectively, as the pressurizing gases. The engine-supplied gaseous hydrogen and gaseous oxygen for fuel and oxidizer tank pressurization during S-IVB flight were routed to the respective facility venting systems.

2.2 TEST CELL

Test Cell J-4, Fig. 2, is a vertically oriented test unit designed for static testing of liquid-propellant rocket engines and propulsion systems at pressure altitudes of 100,000 ft. The basic cell construction provides a 1.5-million-lbf-thrust capacity. The cell consists of four major components (1) test capsule, 48 ft in diameter and 82 ft in height, situated at grade level and containing the test article; (2) spray chamber, 100 ft in diameter and 250 ft in depth, located directly beneath the test capsule to provide exhaust gas cooling and dehumidification; (3) coolant water, steam, nitrogen (gaseous and liquid), hydrogen (gaseous and liquid), and liquid oxygen and gaseous helium storage and delivery systems for operation of the cell and test article; and (4) control building, containing test article controls, test cell controls, and data acquisition equipment. Exhaust machinery is connected with the spray chamber and maintains a minimum test cell pressure before and after the engine firing and exhausts the products of combustion from the engine firing. Before

a firing, the facility steam ejector, in series with the exhaust machinery, provides a pressure altitude of 100,000 ft in the test capsule. A detailed description of the test cell is presented in Ref. 4.

The battleship stage and the J-2 engine were oriented vertically downward on the centerline of the diffuser-steam ejector assembly. This assembly consisted of a diffuser duct (20 ft in diameter by 150 ft in length), a centerbody steam ejector within the diffuser duct, a diffuser insert (13.5 ft in diameter by 30 ft in length) at the inlet to the diffuser duct, and a gaseous nitrogen annular ejector above the diffuser insert. The diffuser insert was provided for dynamic pressure recovery of the engine exhaust gases and to maintain engine ambient pressure altitude (attained by the steam ejector) during the engine firing. The annular ejector was provided to suppress steam recirculation into the test capsule during steam ejector shutdown. The test cell was also equipped with (1) a gaseous nitrogen purge system for continuously inerting the normal air in-leakage of the cell; (2) a gaseous nitrogen repressurization system for raising test cell pressure, after engine cutoff, to a level equal to spray chamber pressure and for rapid emergency inerting of the capsule; and (3) a spray chamber liquid nitrogen supply and distribution manifold for initially inerting the spray chamber and exhaust ducting and for increasing the molecular weight of the hydrogen-rich exhaust products.

An engine component conditioning system was provided for temperature conditioning engine components. The conditioning system utilized a liquid hydrogen-helium heat exchanger to provide cold helium gas for component conditioning. Engine components requiring temperature conditioning were the thrust chamber, crossover duct, start tank discharge valve (tests 24 and 25, only), and main oxidizer valve second-stage actuator. Helium was routed internally through the crossover duct and tubular-walled thrust chamber and externally over the start tank discharge valve. Main oxidizer valve conditioning was achieved by opening the prevalves and permitting propellants into the engine.

2.3 INSTRUMENTATION

Instrumentation systems were provided to measure engine, stage, and facility parameters. The engine instrumentation was comprised of (1) flight instrumentation for the measurement of critical engine parameters and (2) facility instrumentation which was provided to verify the flight instrumentation and to measure additional engine parameters. The flight instrumentation was provided and calibrated by the engine manufacturer; facility instrumentation was initially calibrated and periodically recalibrated at AEDC. Appendix III contains a list of all measured test parameters and the locations of selected sensing points.

Pressure measurements were made using strain-gage-type pressure transducers. Temperature measurements were made using resistance temperature transducers and thermocouples. Oxidizer and fuel turbopump shaft speeds were sensed by magnetic pickup. Fuel and oxidizer flow rates to the engine were measured by turbine-type flowmeters which are an integral part of the engine. The propellant recirculation flow rates were also monitored with turbine-type flowmeters. Vibrations were measured by accelerometers mounted on the oxidizer injector dome and on the turbopumps. Primary engine and stage valves were instrumented with linear potentiometers and limit switches.

The data acquisition systems were calibrated by (1) precision electrical shunt resistance substitution for the pressure transducers and resistance temperature transducer units; (2) voltage substitution for the thermocouples; (3) frequency substitution for shaft speeds and flowmeters; and (4) frequency-voltage substitution for accelerometers.

The types of data acquisition and recording systems used during this test period were (1) a multiple-input digital data acquisition system (MicroSADIC®) scanning each parameter at 40 samples per second and recording on magnetic tape, (2) single-input, continuous-recording FM systems recording on magnetic tape, (3) photographically recording galvanometer oscillographs, (4) direct-inking, null-balance potentiometer-type X-Y plotters and strip charts, and (5) optical data recorders. Applicable systems were calibrated before each test (atmospheric and altitude calibrations). Television cameras, in conjunction with video tape recorders, were used to provide visual coverage during an engine firing, as well as for replay capability for immediate examination of unexpected events.

2.4 CONTROLS

Control of the J-2 engine, battleship stage, and test cell systems during the terminal countdown was provided from the test cell control room. A facility control logic network was provided to interconnect the engine control system, major stage systems, the engine safety cutoff system, the observer cutoff circuits, and the countdown sequencer. A schematic of the engine start control logic is presented in Fig. 6. The sequence of engine events for a normal start and shutdown is presented in Figs. 7a and b. Two control logics for sequencing the stage prevalves and recirculation systems with engine start for simulating engine flight start sequences are presented in Figs. 7c and d.

SECTION III
PROCEDURE

Preoperational procedures were begun several hours before the test period. All consumable storage systems were replenished, and engine inspections, leak checks, and drying procedures were conducted. Propellant tank pressurants and engine pneumatic and purge gas samples were taken to ensure that specification requirements were met. Chemical analysis of propellants was provided by the propellant suppliers. Facility sequence, engine sequence, and engine abort checks were conducted within a 24-hr time period before an engine firing to verify the proper sequence of events. Facility and engine sequence checks consisted of verifying the timing of valves and events to be within specified limits; the abort checks consisted of electrically simulating engine malfunctions to verify the occurrence of an automatic engine cutoff signal. A final engine sequence check was conducted immediately preceding the test period.

Oxidizer dome, gas generator oxidizer injector, and thrust chamber jacket purges were initiated before evacuating the test cell. After completion of instrumentation calibrations at atmospheric conditions, the test cell was evacuated to approximately 0.5 psia with the exhaust machinery, and instrumentation calibrations at altitude conditions were conducted. Immediately before loading propellants on board the vehicle, the cell and exhaust-ducting atmosphere was inerted. At this same time, the cell nitrogen purge was initiated for the duration of the test period, except for the engine firing. The vehicle propellant tanks were then loaded, and the remainder of the terminal countdown was conducted. Temperature conditioning of the various engine components was accomplished as required, using the facility-supplied engine component conditioning system. Engine components which required temperature conditioning were the thrust chamber, the crossover duct, start tank discharge valve (tests 24 and 25, only), and main oxidizer valve second-stage actuator. Table V presents the engine purges and thermal conditioning operations during the terminal countdown and immediately following the engine firing.

SECTION IV
RESULTS AND DISCUSSION

4.1 TEST SUMMARY

Eleven firings of the Rocketdyne J-2 rocket engine (J-2047) were conducted on January 16, 24, 30, and February 6, 1968, during test periods J4-1801-24 through 27. These firings were in support of the S-IVB/S-V J-2 engine developmental testing. Testing was accomplished at pressure altitudes ranging from 85,000 to 109,000 ft at engine start utilizing predicted S-IVB interstage/engine temperature conditions as targets for conditioning engine components.

Test period J4-1801-24 was scheduled to include four firings and one fuel pump performance test. Because of difficulty in controlling start tank temperature, only two firings were accomplished. This difficulty was later attributed to a defective start tank vent and relief valve. All five firings scheduled for test period J4-1801-25 were successfully accomplished. Test period J4-1801-26 was scheduled to include four firings and one pump performance test. During firing 26A the gas generator outlet temperature probe and the augmented spark igniter ignition detect probe failed. After replacement of both probes, firing 26AA was conducted at the same conditions as firing 26A. During this firing, augmented spark igniter ignition detection was erratic. Because of this, firing 26B was terminated at the expiration of the ignition phase timer. All other scheduled firings were cancelled. Test period J4-1801-27 was also scheduled to include four firings and one fuel pump performance test. During shutdown on firing 27A, fires were observed around the engine, and the remaining firings were cancelled.

Test requirements and specific test results are summarized in Table VI. Start and shutdown transient operating times for selected engine valves are presented in Table VII. Figure 8 shows engine start conditions for pump inlets and start and helium tanks. The total firing duration for the four test periods was 188.43 sec. Calculated engine performance for the five 32.5-sec duration firings is presented in Table VIII. Specific test objectives and a brief summary of each firing are presented below.

Firing	Test Objectives	Results
24A	Conduct an S-IVB first burn to evaluate the augmented spark igniter and gas generator temperature transients	The gas generator outlet temperature peaked at 1520°F and experienced a second peak of 1650°F. Fuel pump head/flow

Firing	Test Objectives	Results
24A	and fuel pump low level stall margin.	data showed no significant stall tendency. Post-test inspection showed no augmented spark igniter erosion.
24B	Conduct an S-IVB 80-min restart simulation firing to evaluate engine start transients with maximum start tank energy. Start tank conditions are those expected after an 80-min orbital coast with the proposed narrow band start tank relief valve.	The 7.5-sec duration firing was successfully accomplished, although test requirements were not met. The remaining firings were cancelled.
25A	Conduct an S-IVB first burn with turbine exhaust duct conditioned to minimum expected interstage/engine conditions.	Engine operation appeared normal. Gas generator outlet temperature peaked at 1630°F. Thrust chamber ignition occurred at t_0 + 1.041 sec. Main-stage operation was attained at t_0 + 2.042 sec.
25B	Conduct an S-IVB 80-min orbital restart test. Test requirements and objectives duplicated those for firing 24B.	The gas generator outlet temperature peaked at 1540°F and experienced a second peak of 1650°F. Thrust chamber ignition occurred at t_0 + 0.995 sec. Main-stage operation was attained at t_0 + 2.015 sec.
25C	Conduct an S-IVB first burn with test conditions selected for comparison of firings 25A and 25B to evaluate the effect of turbine hardware temperature on engine start transients. Test conditions also were compared with firing 24A to evaluate the effect of a thrust chamber temperature on engine start transients.	Engine conditioning compared closely with that of firings 24A and 25A. Gas generator initial temperature peak was 1840°F. Insufficient gas generator fuel supply to sustain combustion appeared to exist approximately 45 msec after initial gas generator ignition. Gas generator initial peak temperature was approximately 350°F higher than for firing 24A. Gas generator initial temperature peak

Firing	Test Objectives	Results
25C		was approximately 200°F higher than that of firing 25A.
25D	Conduct an S-IVB restart with requirements selected for comparison with firing 25B to evaluate the effect of a start tank temperature on engine start transients.	The gas generator initial temperature peak was 1870°F and experienced a second peak of 1990°F. Initial temperature peak was about 300°F lower than that of firing 25B.
25E	Conduct a partial transition test to determine the effect of oxidizer dome prime on fuel pump operation.	Fuel pump operation appeared normal.
26A	Conduct a 32.5-sec firing to simulate an S-IVB 6-hr orbital coast restart. Start conditions include low start tank energy, an open propellant utilization valve, and low pump inlet pressures. These conditions are intended to produce maximum chamber pressure buildup time and a minimum stall margin for a restart firing.	Firing terminated prematurely 1.137 sec after t_0 because of an erroneous gas generator outlet overtemperature indication. Post-test inspection revealed the temperature probe had failed.
26AA	Conduct a 32.5-sec firing to simulate an S-IVB 6-hr orbital coast restart. Start conditions include low start tank energy, an open propellant utilization valve, and low pump inlet pressures. These conditions are intended to produce maximum chamber pressure buildup time and a minimum stall margin for a restart firing.	A 32.6-sec firing was successfully completed. Test objectives were satisfactorily met. Chamber pressure buildup time to 550 psia was long (2.769 sec). The high-speed stall margin of 550 gpm was not unusually low. The ignition detect probe failed during the firing.

Firing	Test Objectives	Results
26B	Conduct a 7.5-sec firing to simulate an S-IVB 80-min restart to investigate effects of low start tank energy and warm turbine hardware on engine start transient.	Test objectives were not accomplished since the start transient was not completed. The planned 7.5-sec firing duration was revised to 0.53 sec after the ignition detect probe failed during firing 26AA.
27A	Conduct a 32.5-sec firing to simulate an S-IVB first burn. Evaluate engine buildup time with minimum start energy expected for a first burn.	A 32.6-sec firing was successfully completed. Test objectives were satisfactorily met. A chamber pressure of 550 psia was attained at t_0 + 2.137 sec.

The presentation of the test results in the following sections will consist of a discussion of each engine firing with pertinent comparisons. The data presented will be those recorded on the digital data acquisition system, except as noted.

4.2 TEST RESULTS

4.2.1 Firing J4-1801-24A

The programmed 30-sec duration firing was successfully accomplished. Test conditions at engine start are presented in Table VI. Start and shutdown transient operating times of selected engine valves are shown in Table VII. Engine start and shutdown transients are shown in Fig. 9. Engine ambient pressure at engine start was 102,000 ft and averaged 92,000 ft during main-stage operation (Fig. 10). The propellant utilization valve excursion, which changed mixture ratio from 5.0 to 5.5, is reflected in the increase in combustion chamber pressure at about t_0 + 11 sec. Thermal conditioning history of engine components is shown in Fig. 11.

Test conditions were selected to simulate an S-IVB first burn with a warm thrust chamber, high start tank energy, and low fuel pump inlet pressure. Thrust chamber ignition (chamber pressure attains 100 psia) occurred at t_0 + 0.983 sec, at which time 21 msec of engine vibration (VSC) began. Main-stage operation (chamber pressure attains 550 psia) was obtained at t_0 + 1.914 sec. Main oxidizer valve second-stage movement occurred at t_0 + 0.996 sec. Gas generator outlet temperature peaked at 1520°F and experienced a second peak at 1650°F.

Fuel pump start transient performance is presented in Fig. 12. Fuel pump head/flow data showed no significant stall tendency.

4.2.2 Firing J4-1801-24B

The programmed 7.5-sec duration firing was successfully accomplished. Test conditions at engine start are tabulated in Table VI. Start and shutdown transient operating times of selected engine valves are shown in Table VII. Engine ambient pressure at engine start was 108,000 ft. Figure 13 presents engine ambient pressure and combustion chamber pressure for the duration of the firing. Thermal conditioning history of engine components is shown in Fig. 14. A delay caused by problems with the start tank vent and relief valve resulted in lower than specified turbine hardware temperature.

Engine start and shutdown transients are shown in Fig. 15. Thrust chamber ignition occurred at t_0 + 1.012 with 4 msec of engine vibration (VSC). Chamber pressure reached 550 psia at t_0 + 2.078 sec. The gas generator outlet temperature peaked at 1580°F and experienced a second peak at 1610°F.

Fuel pump start transient performance is shown in Fig. 16. A conservative stall margin was maintained in the region of interest (below 17,500 rpm).

4.2.3 Firing J4-1801-25A

The programmed 32.5-sec duration firing was successfully accomplished. Test conditions at engine start are presented in Table VI. Selected engine valve start and shutdown operating times are shown in Table VII. Thermal conditioning history of engine components is shown in Fig. 17. Engine ambient pressure altitude at engine start was 102,000 ft and averaged 93,000 ft during main-stage operation (Fig. 18).

Test conditions for firing 25A were representative of an S-IVB first burn with turbine hardware conditioned to minimum engine/interstage environmental conditions. Engine start and shutdown transients are shown in Fig. 19. Thrust chamber ignition occurred at t_0 + 1.041 sec, at which time 22 msec of engine vibration (VSC) began. Main-stage operation was attained at t_0 + 2.084 sec. Gas generator outlet temperature peaked at 1630°F.

Fuel pump start transient performance is shown in Fig. 20. A conservative stall margin was maintained throughout the start transient.

Net positive suction head available during the start transient is compared with minimum engine model specification in Fig. 21. Fuel pump operation appeared satisfactory.

4.2.4 Firing J4-1801-25B

The programmed 7.5-sec duration firing was successfully accomplished. Test conditions at engine start are presented in Table VI. Start and shutdown transient operating times of selected engine valves are shown in Table VII. Engine ambient pressure altitude at engine start was 102,500 ft. Figure 22 presents engine ambient and combustion chamber pressure for the duration of the firing. The thermal conditioning history of engine components is shown in Fig. 23.

Test conditions for this firing were representative of an S-IVB restart with maximum expected start tank energy after an 80-min orbital coast time simulating start tank conditions expected from a proposed narrow band start tank relief valve. Engine start and shutdown transients are shown in Fig. 24. Thrust chamber ignition occurred at t_0 + 0.995 sec, at which time 10 msec of engine vibration (VSC) began. Main-stage operation was attained at t_0 + 2.015 sec. Gas generator outlet temperature peaked at 1540°F and experienced a second peak of 1650°F. This second peak was influenced by the main oxidizer valve remaining at the 14-deg position until t_0 + 1.137 sec.

Fuel pump start transient performance is shown in Fig. 25. A conservative stall margin was maintained throughout the start transient.

4.2.5 Firing J4-1801-25C

The programmed 32.5-sec duration engine firing was successfully accomplished. Test conditions at engine start are shown in Table VI. Start and shutdown transient operating times of selected engine valves are shown in Table VII. Thermal conditioning history of engine components is shown in Fig. 26. Engine ambient pressure altitude at engine start was 106,500 and averaged 93,000 ft during main-stage operation (Fig. 27).

Test conditions for firing 25C were representative of an S-IVB first burn utilizing the coldest expected thrust chamber temperature at engine start. Figure 28 shows engine start and shutdown transients. Thrust chamber ignition occurred at t_0 + 0.998 sec, at which time 15 msec of engine vibration began. Main-stage operation was attained at t_0 + 1.960 sec.

Gas generator outlet temperature peaked at 1840°F and experienced no second peak. Initial gas generator ignition occurred 0.655 sec after t_0. Since fuel pump discharge pressure was lower than gas generator pressure at this time, fuel for ignition was gaseous hydrogen from the start tank. After ignition, low grade combustion existed for 45 msec, as indicated by the rapid decrease in gas generator chamber and fuel injector pressures. As indicated by the slope of gas generator chamber pressure after reignition, gas generator power was low, allowing oxidizer pump speed to decay more than usual. The higher than normal oxidizer pump speed decay lowered gas generator oxidizer/fuel mixture ratio, thus preventing a second peak.

Fuel pump start transient performance data are presented in Fig. 29. A conservative stall margin was maintained throughout the start transient. Net positive suction head available is compared with the minimum engine model specification in Fig. 30. Fuel pump operation appeared satisfactory.

Test conditions for firing 25C were selected to duplicate firing 24A, except for thrust chamber temperature at engine start. Thrust chamber temperatures for firings 24A and 25C were -110°F and -280°F, respectively. The increased thrust chamber resistance during the start transient (Fig. 31) on firing 24A is reflected in a higher fuel pump discharge pressure. This higher pump discharge pressure forced more fuel into the gas generator; thus, the gas generator outlet temperature initial peak (Fig. 32) is 325°F less than that of firing 25C.

Test conditions for firing 25C were also selected to duplicate firing 25A, except for turbine hardware temperature at engine start. Turbine hardware temperatures at engine start were -111°F and +21°F for firings 25A and 25C, respectively. Oxidizer pump speeds for these two firings reflect the temperature difference. Peak oxidizer pump spin speed for firing 25A was 3263 rpm, whereas peak oxidizer pump spin speed for firing 25C was 3415 rpm. The higher pump spin speed of firing 25C produced higher oxidizer pump discharge pressure, causing the first temperature peak to be about 200°F higher than that of firing 25A, as shown in Figs. 33 and 34.

4.2.6 Firing J4-1801-25D

The programmed 7.5-sec duration engine firing was successfully accomplished. Test conditions at engine start are presented in Table VI. Start and shutdown transient operating times of selected engine valves are tabulated in Table VII. Thermal conditioning history of engine components is shown in Fig. 35.

Engine start and shutdown transients are presented in Fig. 36. Engine ambient pressure altitude at engine start was 109,000 ft. Combustion chamber pressure and engine ambient pressure are shown in Fig. 37. Thrust chamber ignition occurred at t_0 + 0.987 sec at which time 16 msec of engine vibration (VSC) began. Chamber pressure attained 550 psia at t_0 + 2.023 sec. The gas generator outlet temperature peaked at 1870°F and experienced a second peak at 1990°F.

Fuel pump start transient performance is shown in Fig. 38. A conservative stall margin was maintained in the region of interest, below 17,500 rpm.

Test conditions for firing 25D were selected to duplicate those of firing 25B except for start tank temperature. Start tank temperature at engine start on firing 25B was -216°F, whereas start tank temperature for firing 25D was -267°F. This temperature difference caused oxidizer pump speed (Fig. 39) to be 100 rpm higher on firing 25D than on firing 25B. This pump speed increase is reflected in both gas generator outlet temperature and main oxidizer valve operation, as shown in Fig. 40. Gas generator outlet temperature initial peak was approximately 330°F higher on firing 25D. The main oxidizer valve remained at the 14-deg position 44 msec longer on firing 25D because of a higher hydraulic closing torque across the valve gate.

4.2.7 Firing J4-1801-25E

The programmed 1.150-sec duration fuel pump performance test was successfully accomplished. Test conditions at engine start are presented in Table VI. Start and shutdown transient operating times of selected engine valves are presented in Table VII. Engine ambient pressure at engine start was 107,000 ft. Engine ambient pressure and combustion chamber pressure for the duration of the firing are presented in Fig. 41. Thermal conditioning history of engine components is shown in Fig. 42.

Engine start and shutdown transients are shown in Fig. 43. Thrust chamber ignition occurred at t_0 + 1.030 sec, at which time 32 msec of engine vibration (VSC) began. Gas generator initial peak was 1390°F.

Fuel pump start transient performance is presented in Fig. 44. Stall margin was conservative. Net positive suction head available is compared with minimum engine model specification in Fig. 45. Pump operation was satisfactory.

4.2.8 J4-1801-26A

The programmed 32.5-sec firing, preceded by an 8-sec fuel lead, was terminated prematurely at t_0 + 1.137 sec. A malfunction of the gas generator outlet temperature probe caused an erroneous indication of excessive temperature and activated the engine safety cutoff circuitry. In addition, a checkout of the augmented spark igniter ignition detect system indicated that the probe was electrically shorted to ground. Both probes were replaced, and testing continued.

Second-stage movement of the main oxidizer valve began at t_0 + 1.047 sec. Main chamber ignition occurred at t_0 + 1.110 sec, at which time 78 msec of engine vibration (VSC) began. A thermal conditioning history of the crossover duct, main oxidizer valve second-stage actuator, and thrust chamber throat before firing 26A engine start are presented in Fig. 46. Engine ambient and combustion chamber pressures are shown in Fig. 47. Pressure altitude at engine start was 97,000 ft.

A summary of engine valve operating times for start and shutdown is shown in Table VII. All valve operations were normal.

4.2.9 Firing J4-1801-26AA

Firing 26AA was 32.6 sec in duration with a propellant utilization valve excursion from full open to full closed at t_0 + 25 sec. This S-IVB 6-hr orbital coast restart simulation firing was a repeat of firing 26A. A thermal conditioning history of the crossover duct, main oxidizer valve second-stage actuator, and thrust chamber throat before engine start is presented in Fig. 48. Fuel lead duration was 8 sec.

Engine start and shutdown transients of primary engine parameters are shown in Fig. 49. Second-stage movement of the main oxidizer valve began at t_0 + 1.021 sec. Main chamber ignition occurred at t_0 + 1.113 sec with 42 msec of engine vibrations (VSC) beginning at 1.081 sec for 10 msec and continuing for another 40 msec. The gas generator outlet temperature peaked at 1250°F and decreased to a minimum of 580°F (lowest observed to date at AEDC after the initial peak) before increasing to a steady-state value of approximately 960°F before the propellant utilization valve excursion. A combustion chamber pressure of 550 psia was attained at t_0 + 2.769 sec, comparatively long because of the low start energy conditions and open propellant utilization valve. Engine ambient and combustion chamber pressures for the firing duration are shown in Fig. 50. Pressure altitude at engine start was 91,000 ft.

Start transient fuel pump head/flow data are compared with the stall inception curve (provided by the engine manufacturer) in Fig. 51. The minimum stall margin observed was 550 gpm at approximately 19,000 rpm.

A summary of engine valve operating times for start and shutdown is presented in Table VII. Valve operations were normal.

A checkout of the ignition detect system after this firing indicated the probe was not functioning properly.

4.2.10 Firing J4-1801-26B

Firing 26B was a scheduled 7.5-sec firing to simulate an S-IVB 80-min restart and investigate effects of low start tank energy and warm turbine hardware on engine start transient. The planned 7.5-sec firing duration was changed to 0.53 sec after the ignition detect probe failed during firing 26AA. Consequently, the start transient was not completed, and the firing results are inconclusive.

4.2.11 Firing J4-1801-27A

Firing 27A was 32.6 sec in duration with a propellant utilization valve excursion from null to full closed at t_0 + 17 sec. Flight prevalve sequencing for J-2 engine first burn was utilized on this firing with a 3-sec fuel lead. A thermal conditioning history of the crossover duct, main oxidizer valve second-stage actuator, and thrust chamber throat before engine start is presented in Fig. 52.

Engine start and shutdown transients of primary engine parameters are shown in Fig. 53. Second-stage movement of the main oxidizer valve began at t_0 + 1.012 sec. Main chamber ignition occurred at t_0 + 1.076 sec, at which time 20 msec of engine vibrations (VSC) began. Engine ambient and combustion chamber pressures for the firing duration are shown in Fig. 54. Pressure altitude at engine start was 85,000 ft.

Start transient fuel pump head/flow data are compared with the stall inception curve (provided by the engine manufacturer) in Fig. 55. The minimum stall margin was 450 gpm at approximately 19,000 rpm.

A summary of engine valve operating times for start and shutdown is presented in Table VII. All valve operations were normal.

The remaining scheduled firings were cancelled because of an oxidizer leak, as evidenced by test cell fires observed at shutdown. Heavy vapors were noted emitting from the engine-stage interface during the firing.

4.3 POST-TEST INSPECTION

4.3.1 Test Period J4-1801-24

The start tank vent and relief valve was found to be defective after this test period and was replaced. There was no apparent erosion of the augmented spark igniter chamber.

4.3.2 Test Period J4-1801-25

Oscillograph data indicated that the oxidizer turbine bypass valve did not move during firing 25E. The valve was subsequently replaced before test 26. A post-test inspection of the augmented spark igniter chamber indicated no erosion.

4.3.3 Test Period J4-1801-26

The gas generator outlet temperature and augmented spark igniter ignition detect probes failed during firing 26A and were replaced before firing 26AA. The replacement ignition detect probe was erratic during firing 26AA and was replaced after the test period. There was no apparent erosion of the augmented spark igniter chamber.

4.3.4 Test Period J4-1801-27

There was an apparent oxidizer leak during firing 27A, as evidenced by dense vapors from the engine-stage interface vicinity. Some test cell fire was also observed at shutdown of firing 27A. A post-fire leak check of the oxidizer feed system indicated a small leak upstream of the prevalve. A post-fire inspection of the augmented spark igniter chamber indicated no apparent erosion.

SECTION V
SUMMARY OF RESULTS

The results of the 11 firings of the Rocketdyne J-2 rocket engine conducted on January 16, 24, and 30 and February 6, 1968, in Test Cell J-4 are summarized as follows:

1. Thrust chamber temperature effect on gas generator temperature was determined from comparison of firings 25C and 24A to be 350°F higher for a 170°F colder thrust chamber temperature.

2. It was determined that a 51°F colder start tank gas temperature resulted in a 300°F higher gas generator outlet temperature by comparison of firings 25B and 25D.

3. Comparison of firings 25C and 25A showed that the colder turbine hardware on firing 25A (-111°F versus +21°F) resulted in a 150-rpm lower peak oxidizer pump speed. Gas generator outlet temperature was 210°F higher on firing 25C.

4. The minimum high-speed stall margin recorded was 450 gpm at approximately 19,000 rpm. This was an S-IVB first burn simulation firing (27A) with minimum starting energy.

5. Low grade combustion existed in the gas generator for approximately 45 msec after the initial gas generator ignition during firing 25C start transient.

6. The time required for chamber pressure buildup to 550 psia during firing 26AA was 2.769 sec, the second longest recorded at AEDC for a J-2 engine, S-IVB simulation firing. This simulated a 6-hr orbital coast restart firing and included low start energy and an open propellant utilization valve at engine start. The gas generator outlet temperature decreased to 580°F after the initial peak before increasing to steady state.

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1. Dublin, M., Sissenwine, N., and Wexler, H. U. S. Standard Atmosphere, 1962. December 1962.

2. Rafferty, C. A. "Altitude Developmental Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Test J4-1801-23)." AEDC-TR-68-102, June 1968.

3. "J-2 Rocket Engine, Technical Manual Engine Data." R-3825-1, August 1965.

4. Test Facilities Handbook (6th Edition). "Large Rocket Facility, Vol. 3." Arnold Engineering Development Center, November 1966.

5. "Engine Model Specification Liquid-Propellant Rocket Engine-Rocketdyne Model J-2." R-2158C3, January 1966.

APPENDIXES

I. ILLUSTRATIONS
II. TABLES
III. INSTRUMENTATION
IV. METHODS OF CALCULATIONS (PERFORMANCE PROGRAM)

Fig. 1 Test Cell J-4 Complex

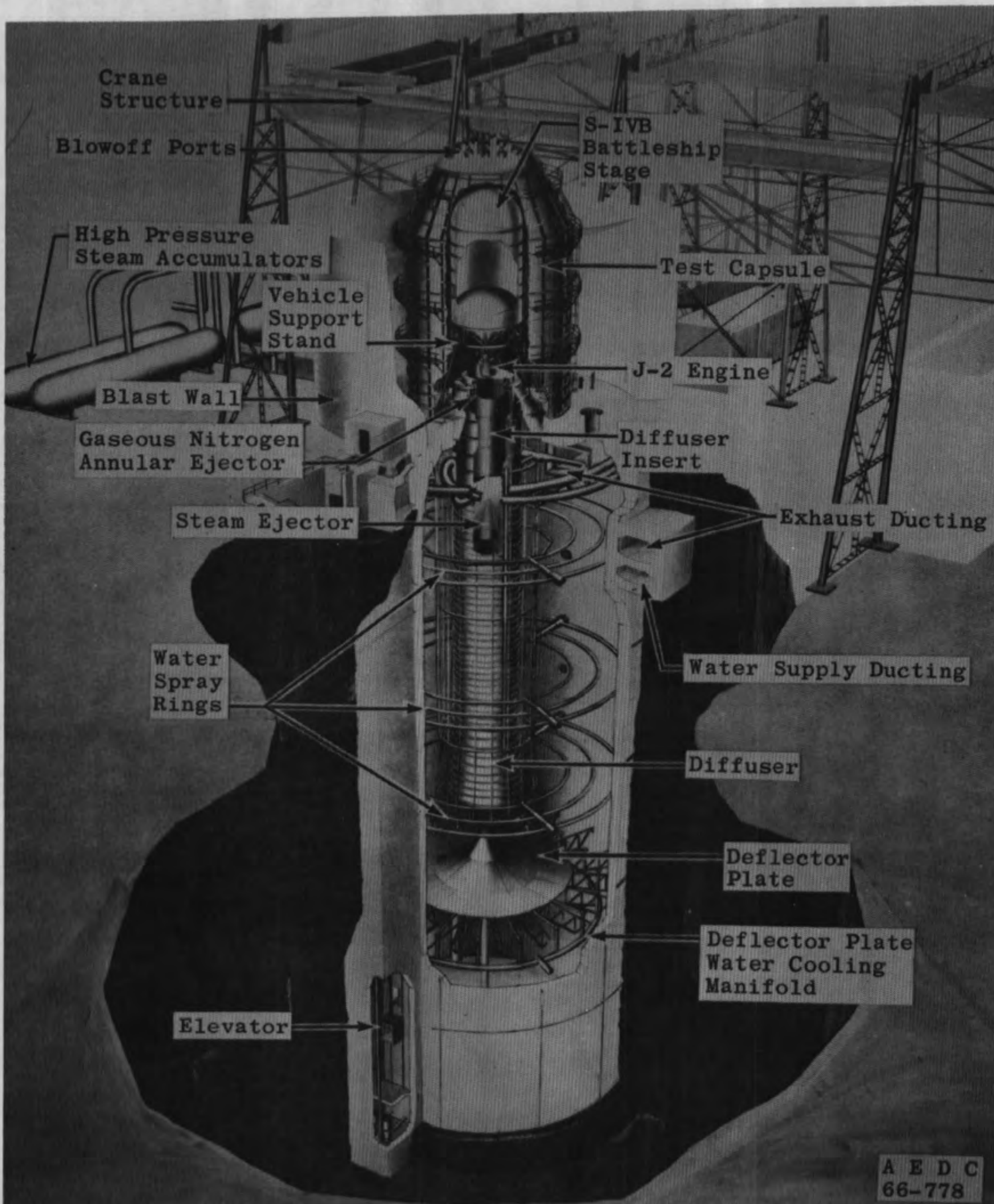


Fig. 2 Test Cell J-4, Artist's Conception

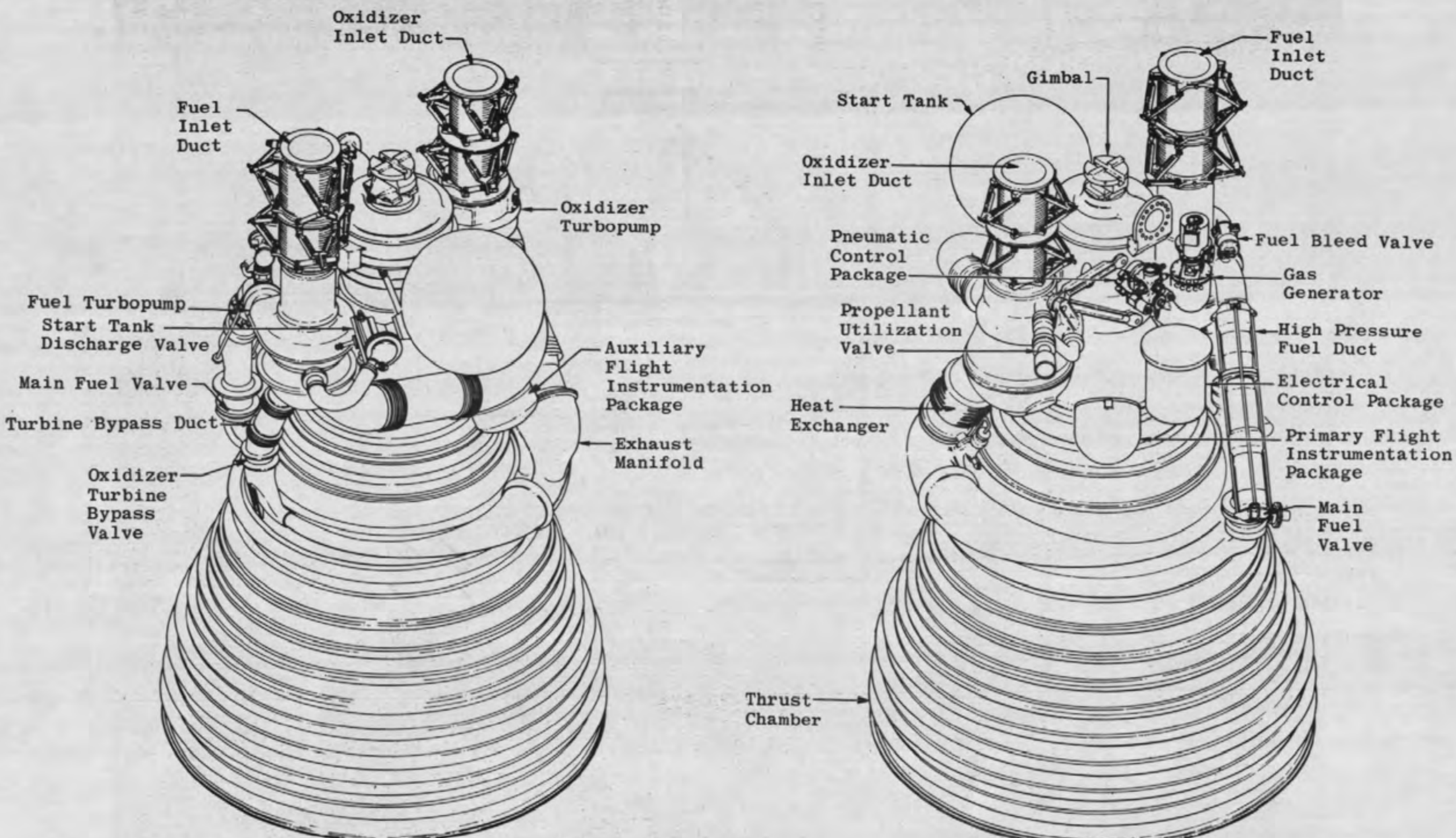


Fig. 3 Engine Details

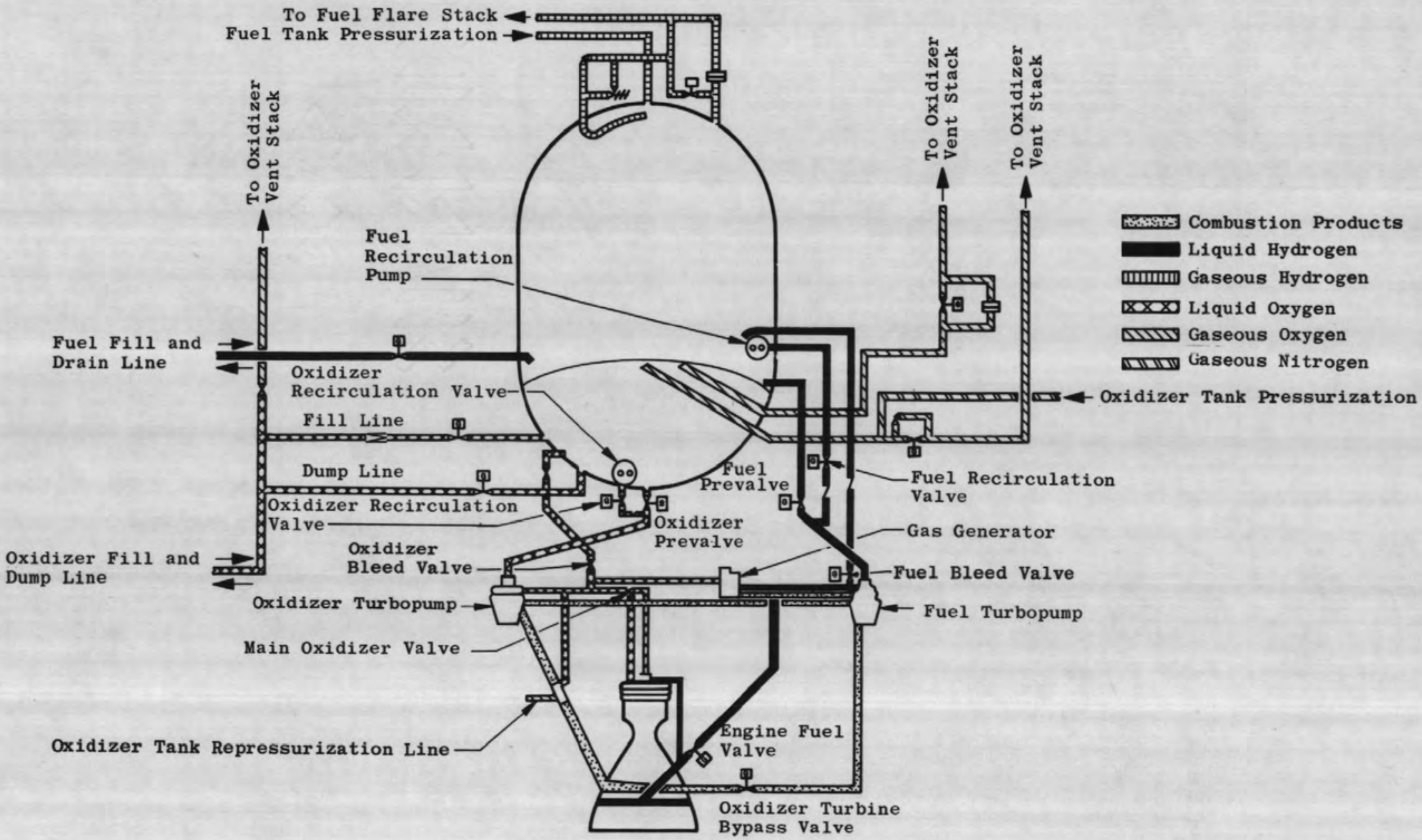


Fig. 4 S-IVB Battleship Stage/J-2 Engine Schematic

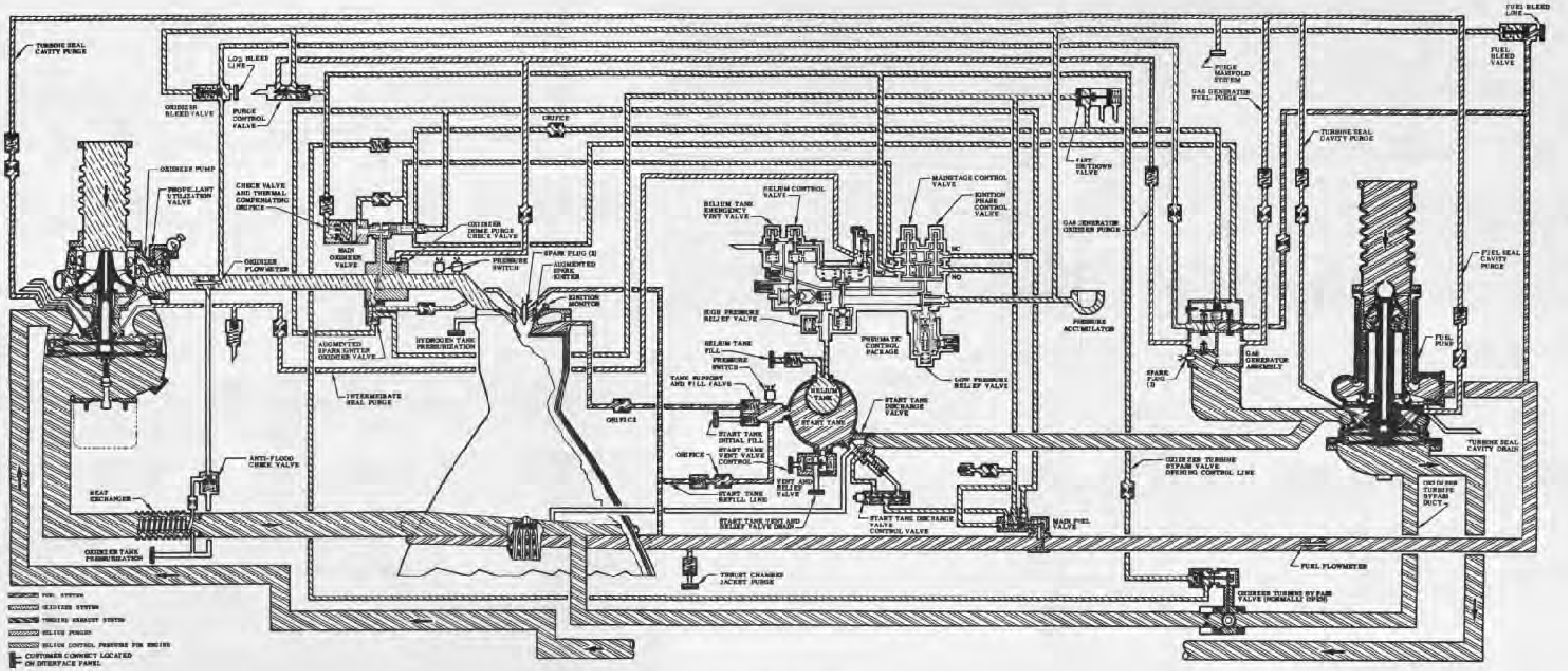


Fig. 5 Engine Schematic

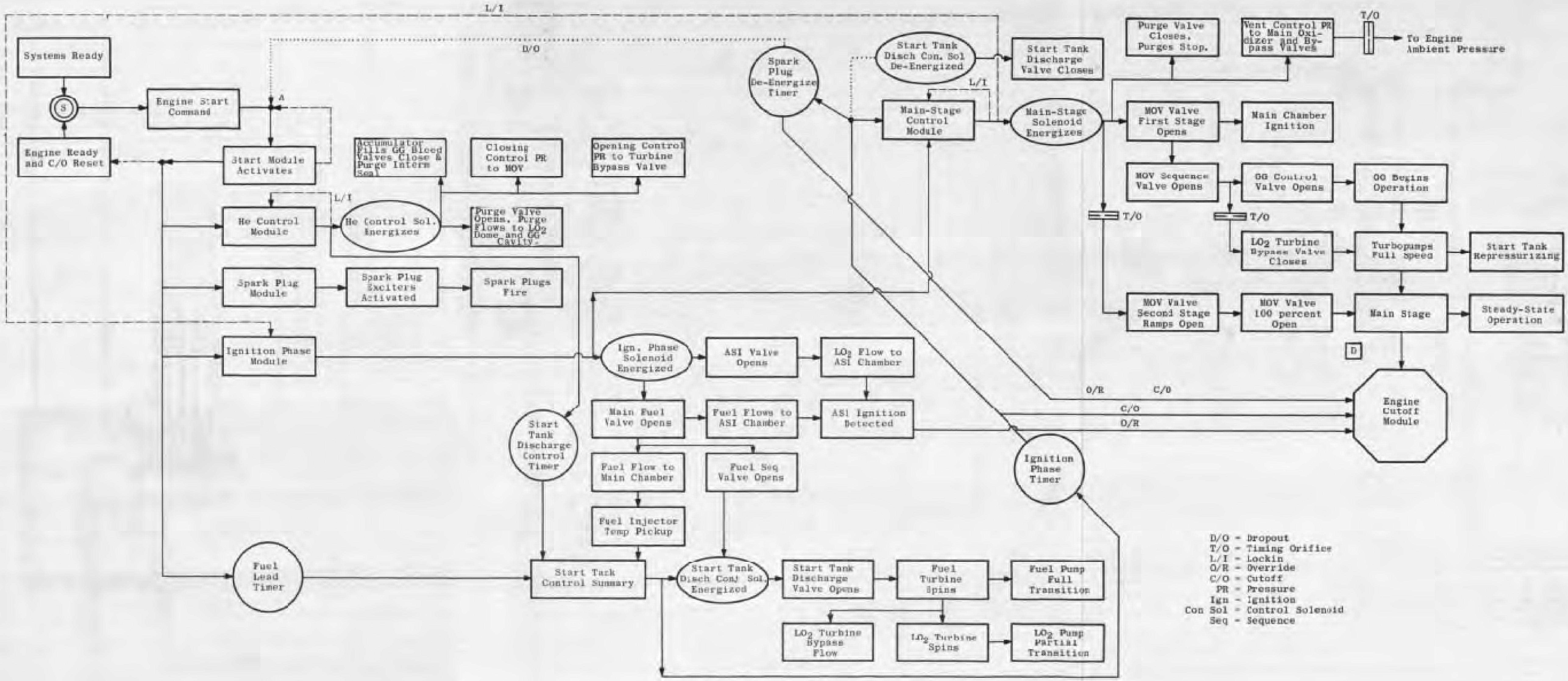
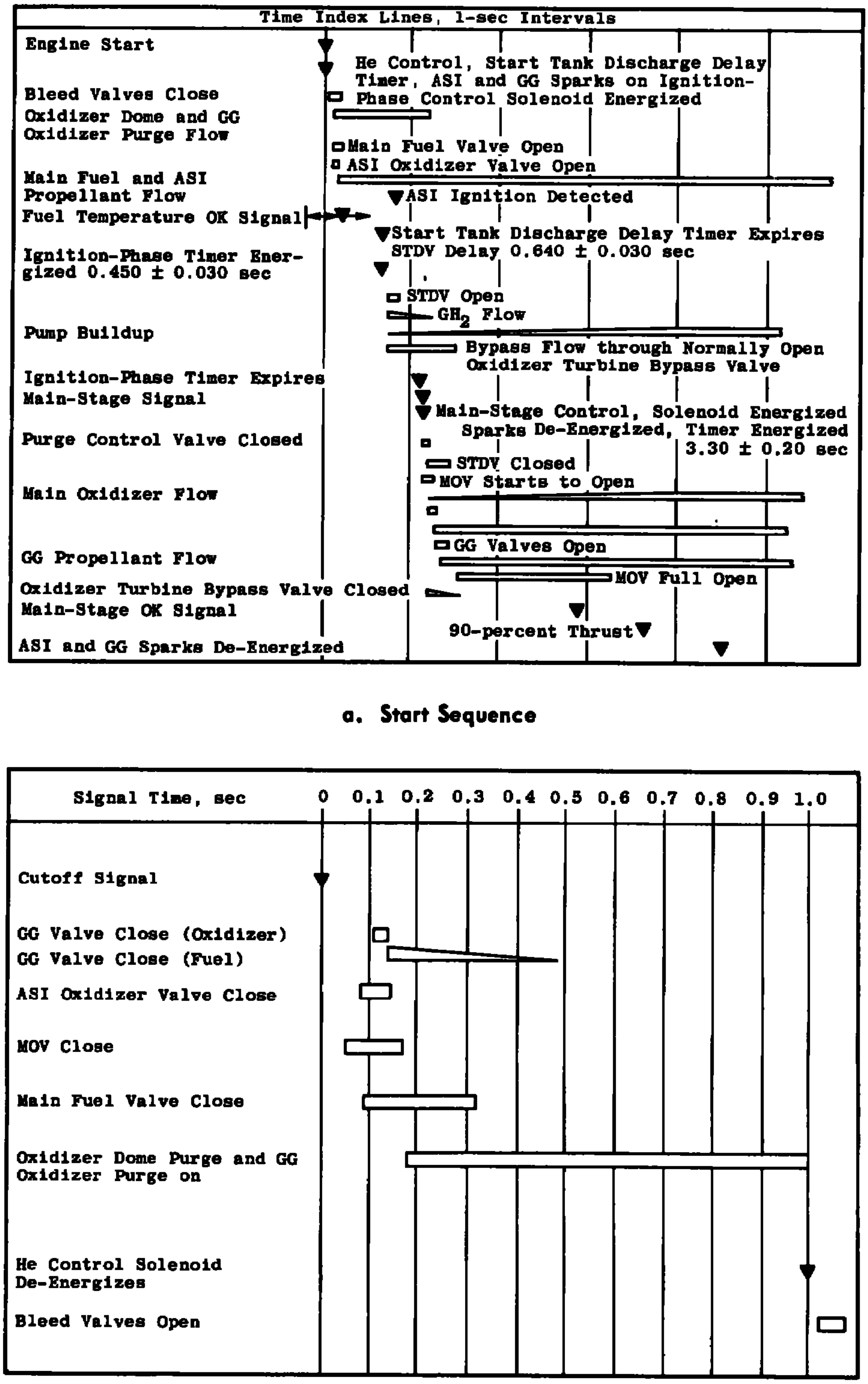


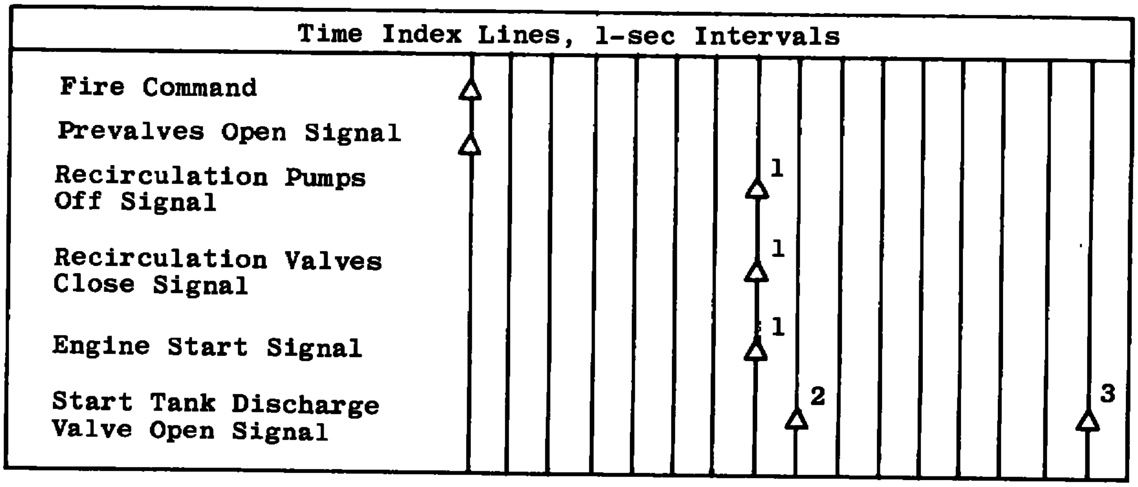
Fig. 6 Engine Start Logic Schematic



a. Start Sequence

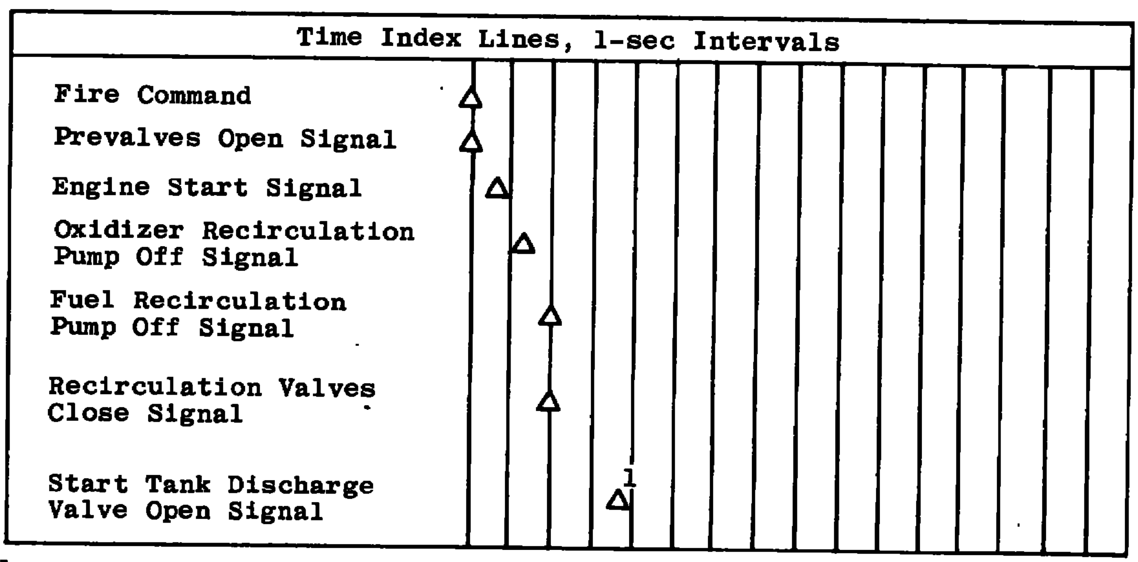
b. Shutdown Sequence

Fig. 7 Engine Start and Shutdown Sequence



[1] Nominal Occurrence Time (Function of Prevalves Opening Time)
[2] One-sec Fuel Lead (S-II/S-V and S-IVB/S-IB)
[3] Eight-sec Fuel Lead (S-IVB/S-V and S-IB Orbital Restart)

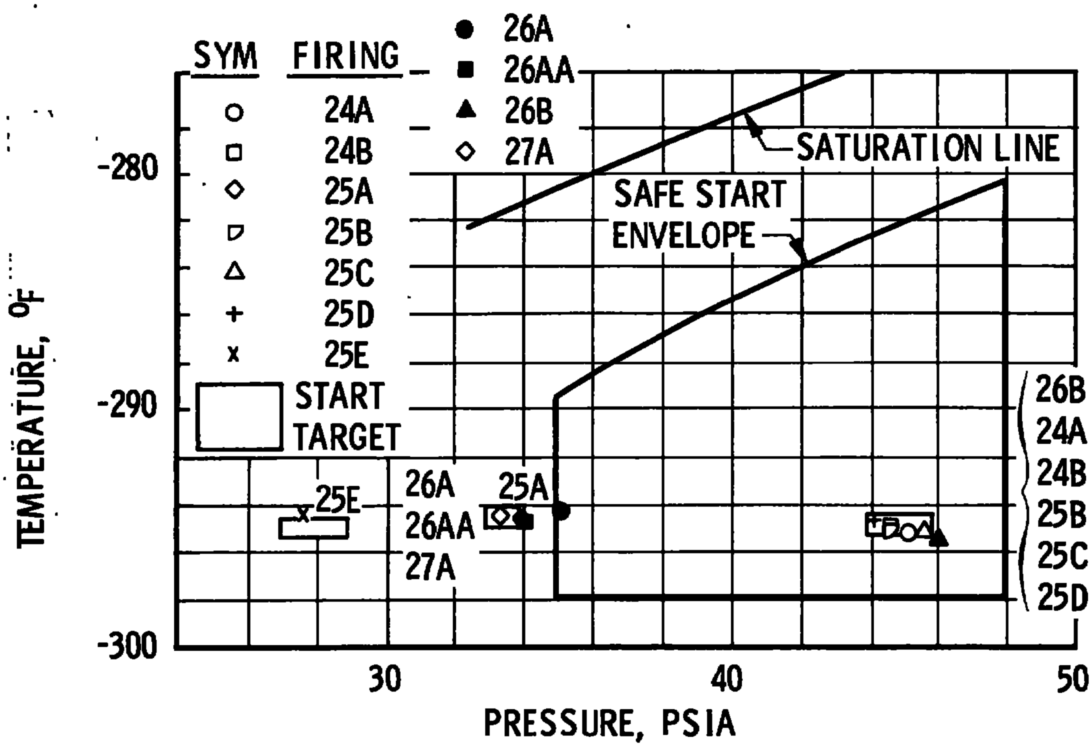
c. Normal Logic Start Sequence



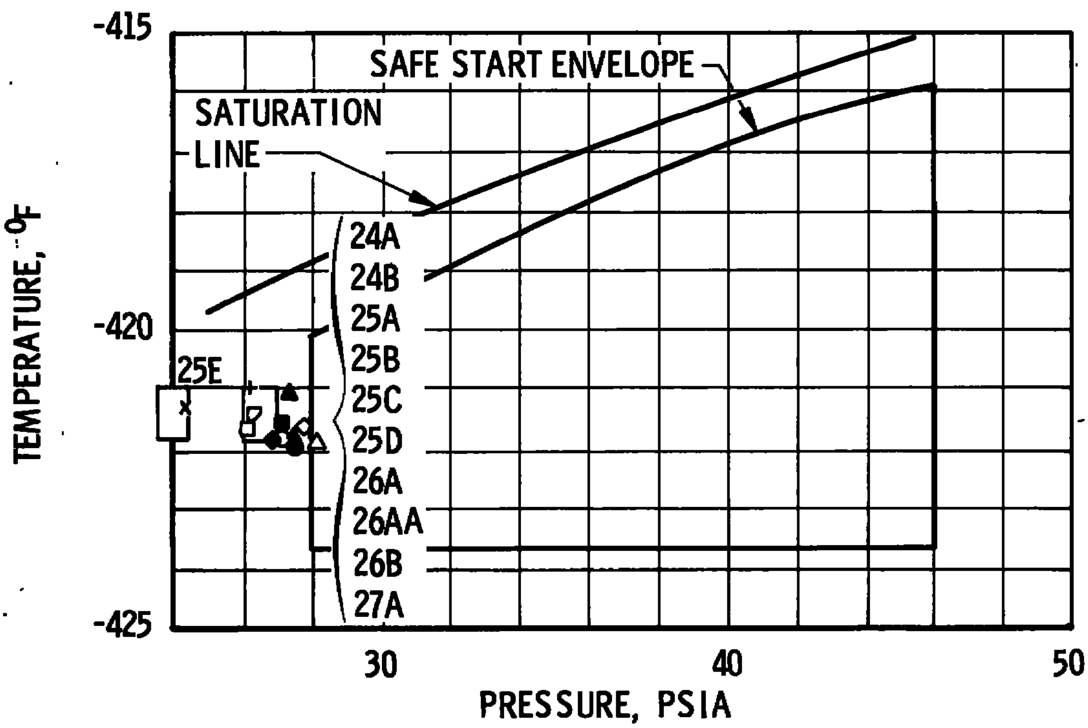
[1] Three-sec Fuel Lead (S-IVB/S-V First Burn)

d. Auxiliary Logic Start Sequence

Fig. 7 Concluded

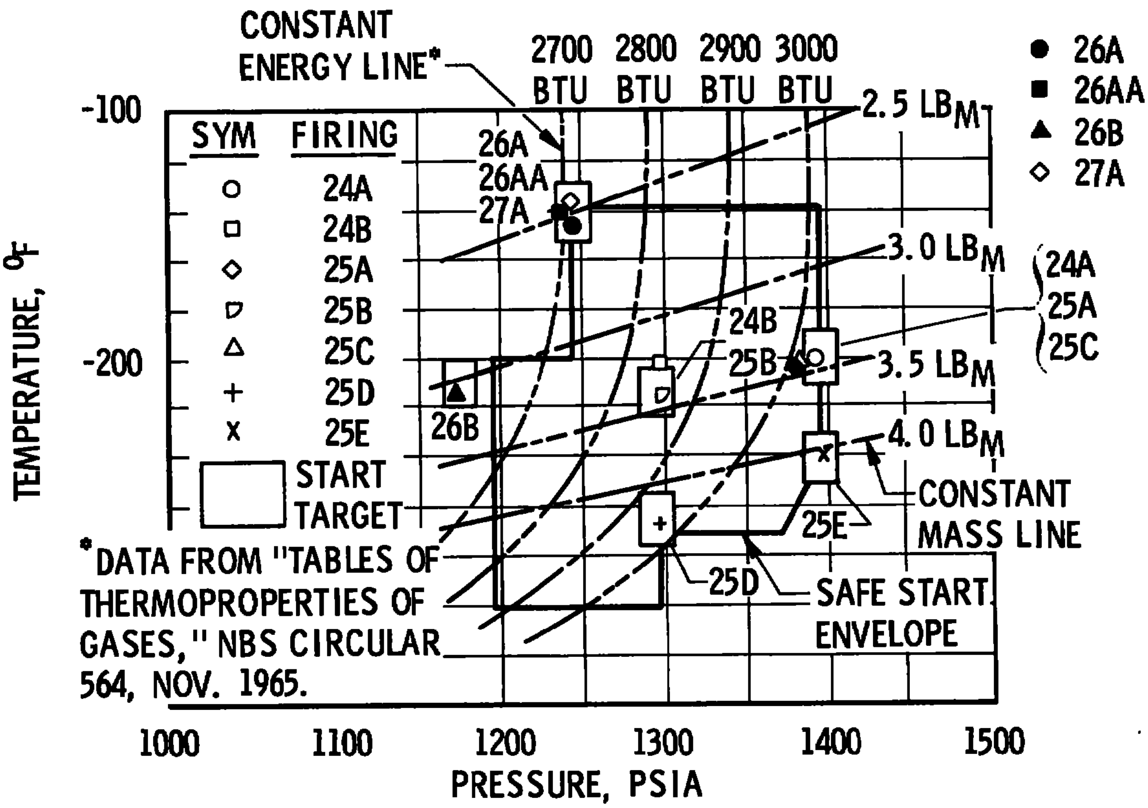


a. Oxidizer Pump Inlet

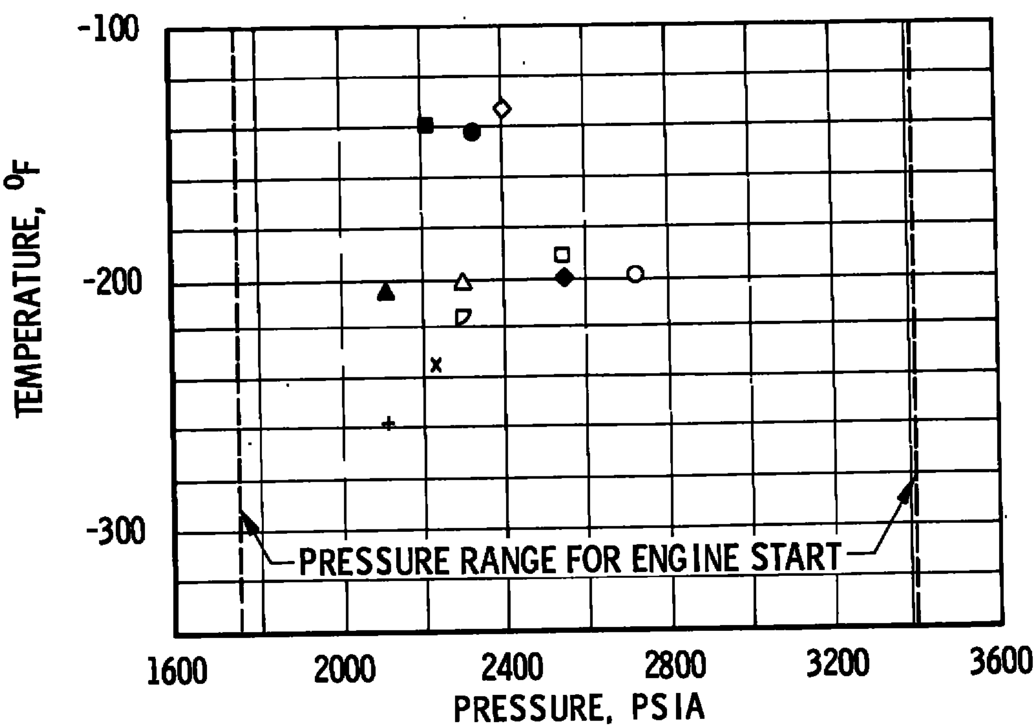


b. Fuel Pump Inlet

Fig. 8 Engine Start Conditions for Pump Inlets, Start Tank, and Helium Tank

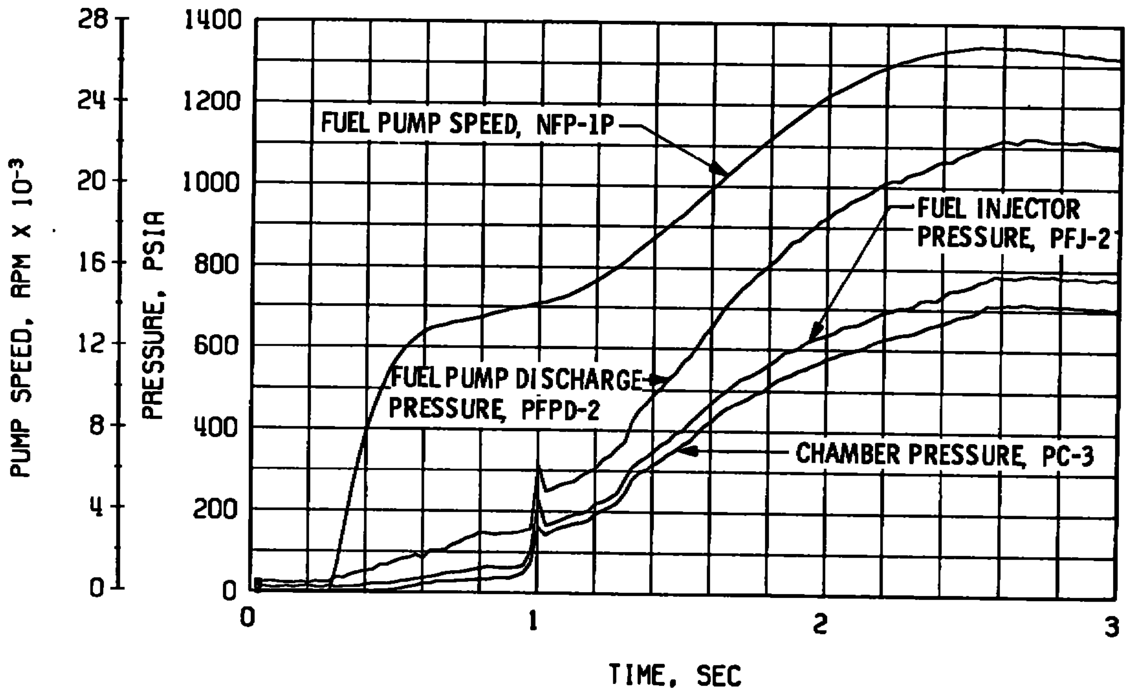


c. Start Tank

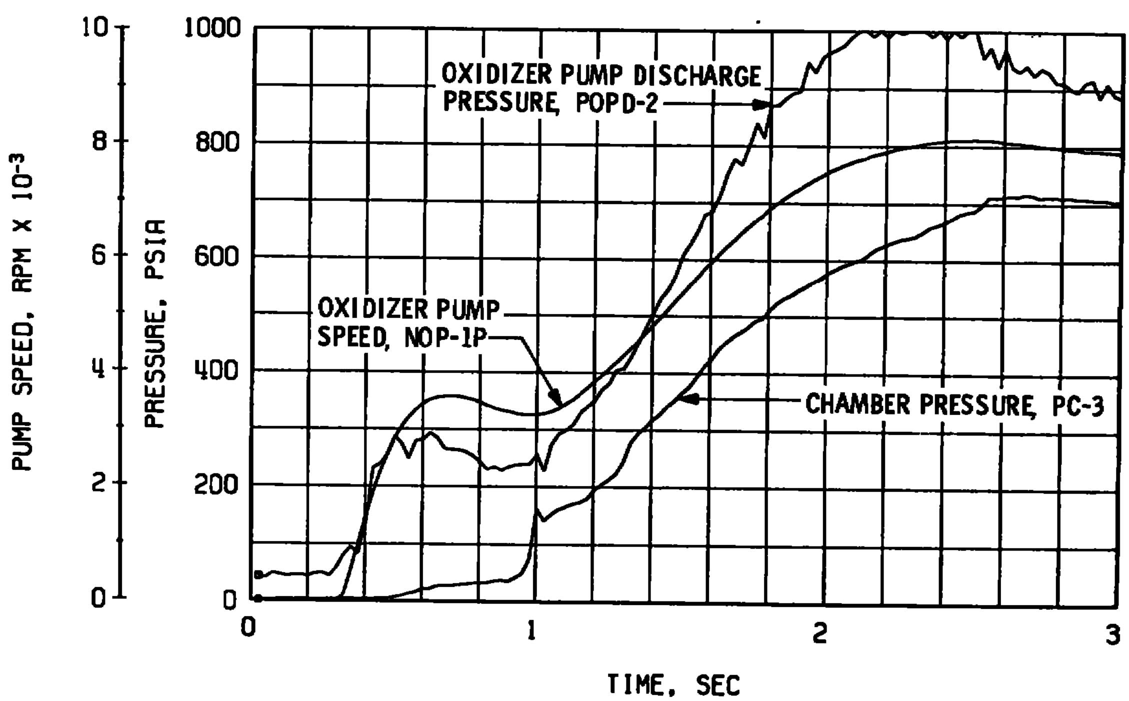


d. Helium Tank

Fig. 8 Concluded

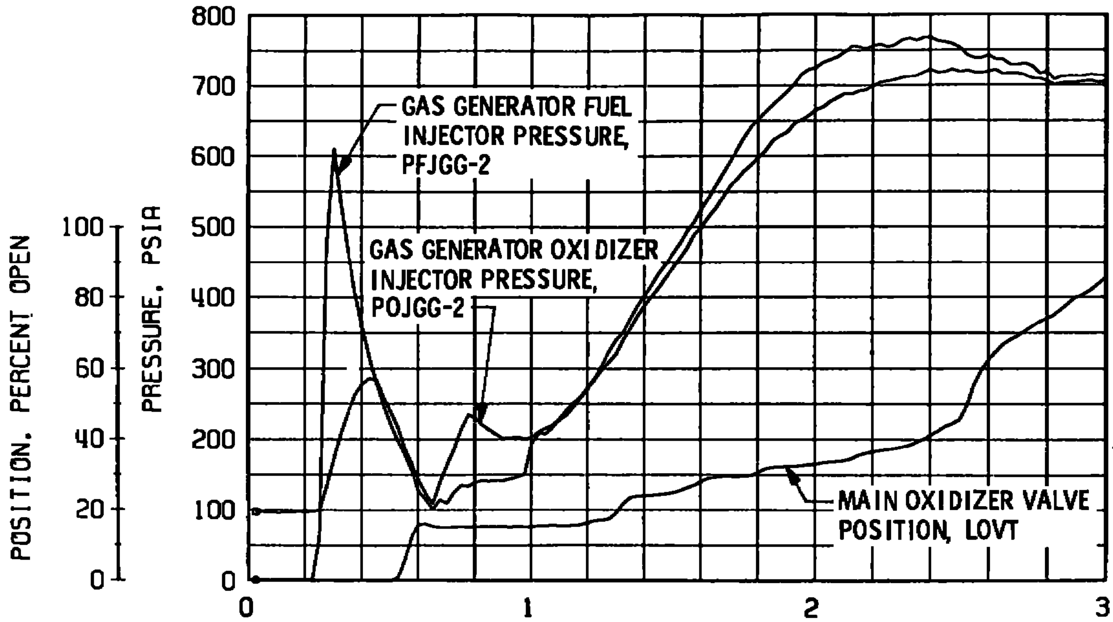


a. Thrust Chamber Fuel System, Start

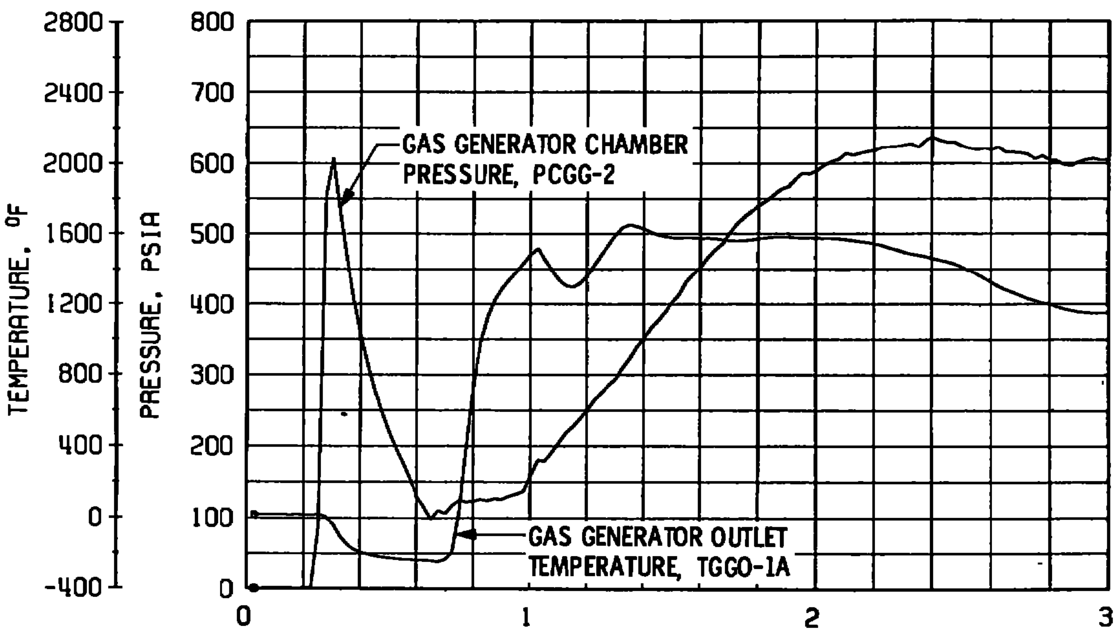


b. Thrust Chamber Oxidizer System, Start

Fig. 9 Engine Transient Operation, Firing 24A

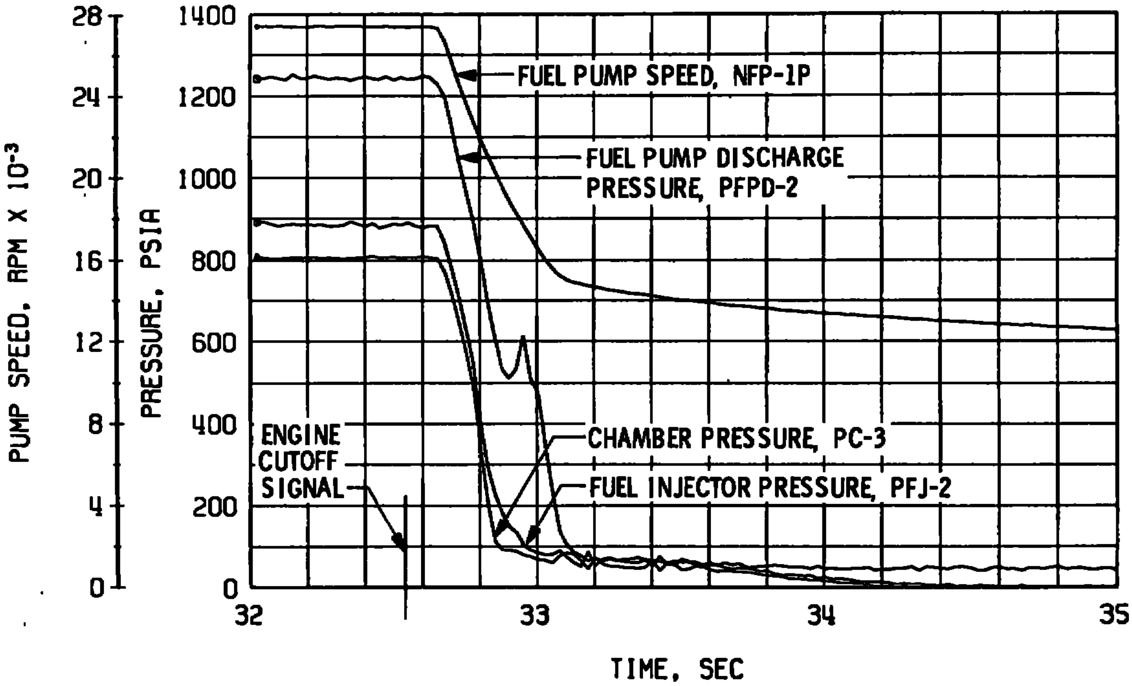


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

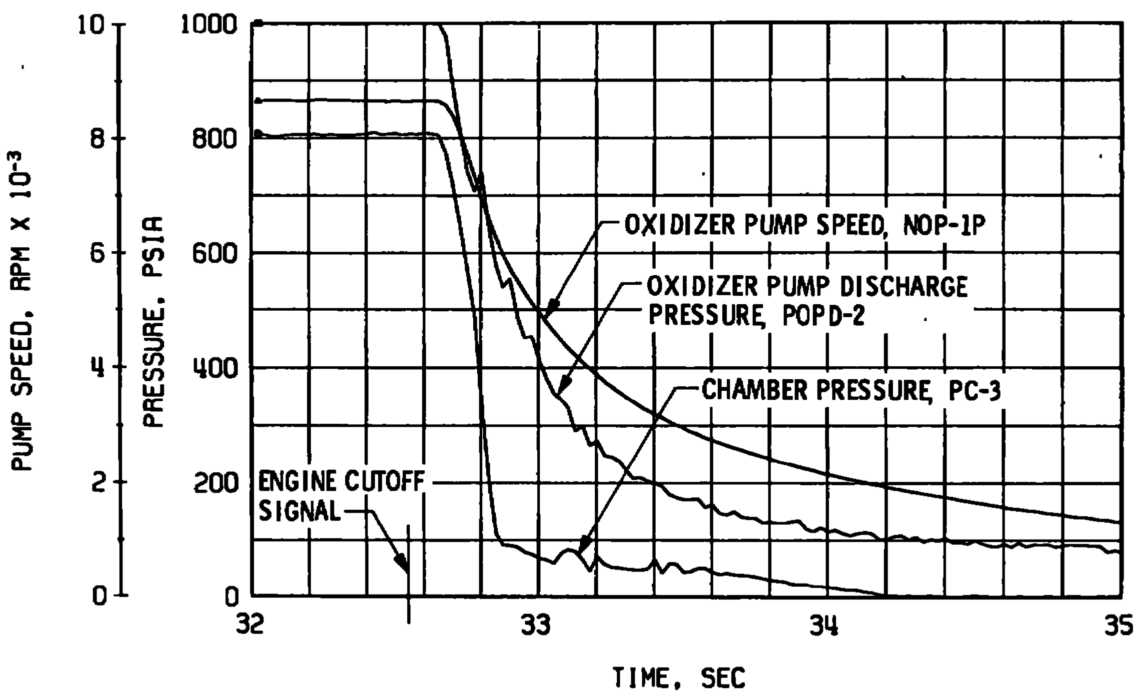


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 9 Continued

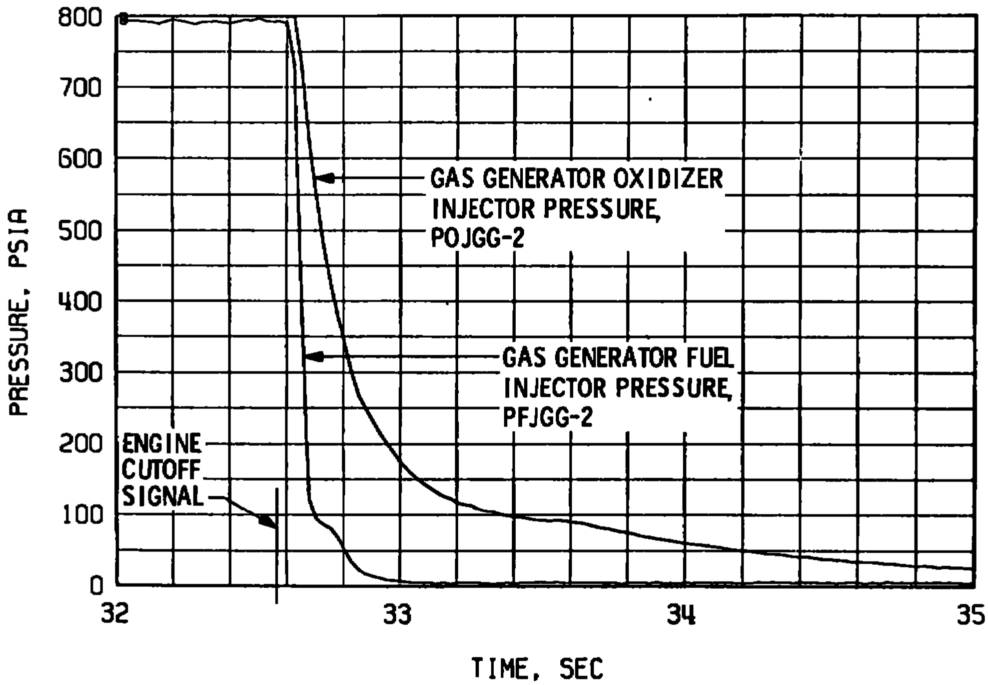


e. Thrust Chamber Fuel System, Shutdown

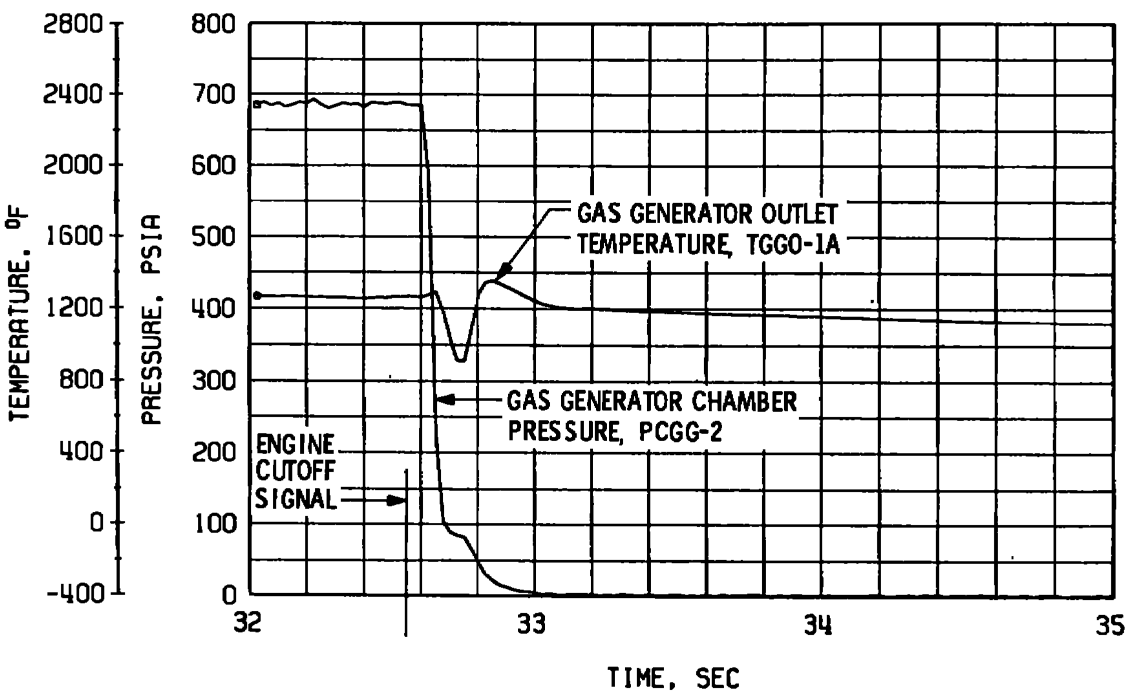


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 9 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown
Fig. 9 Concluded

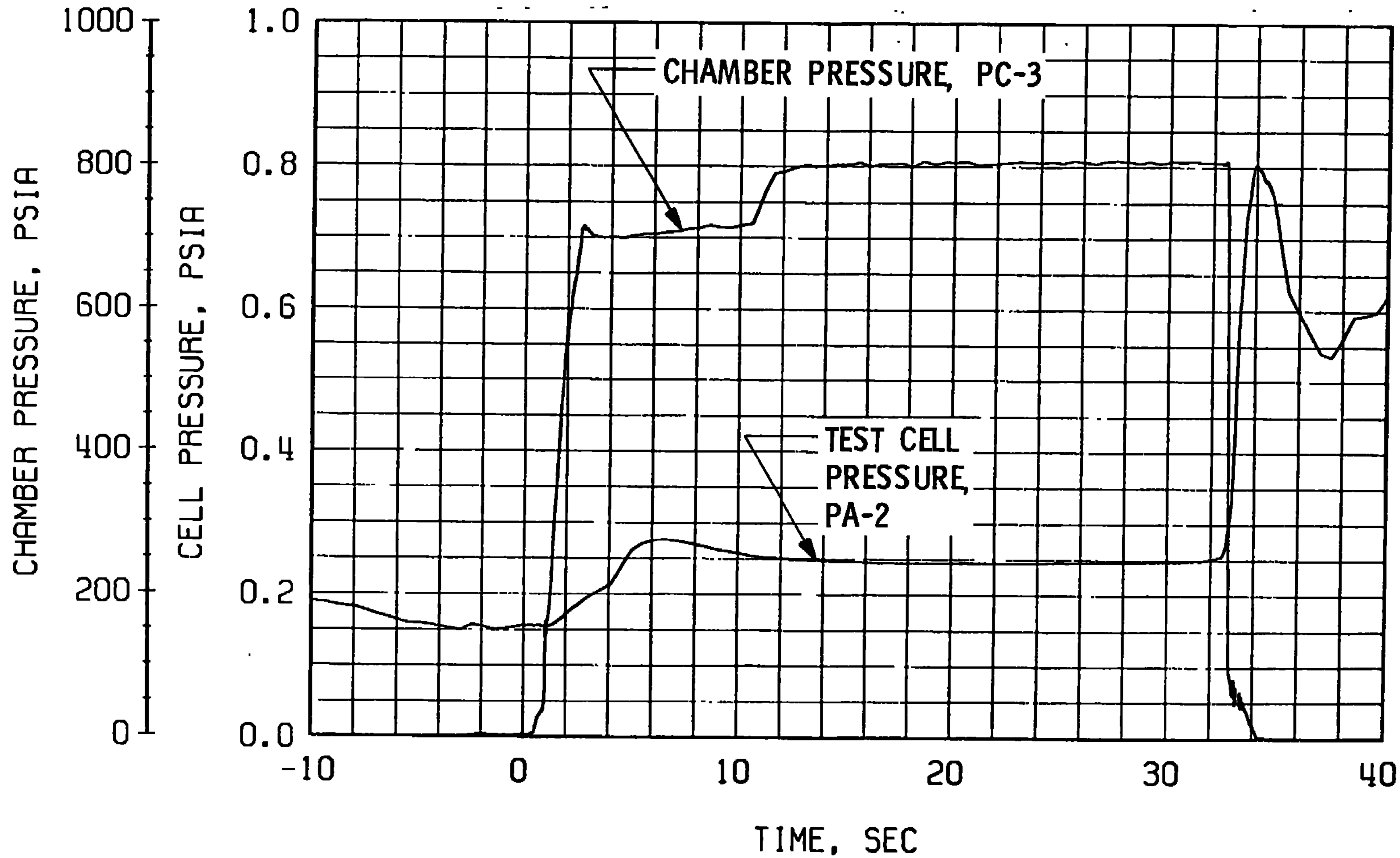
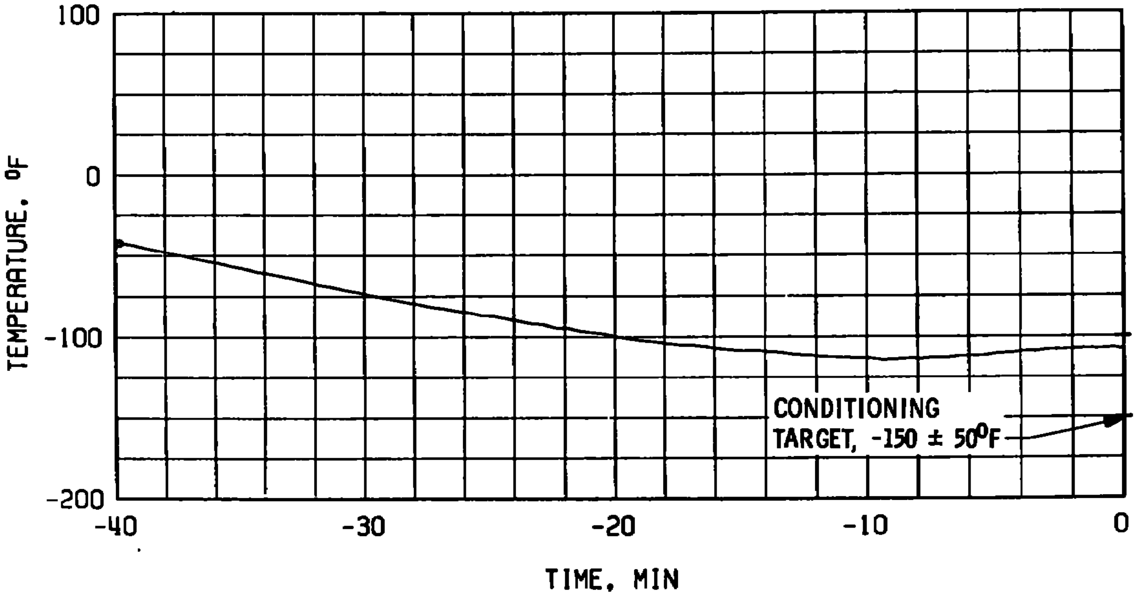
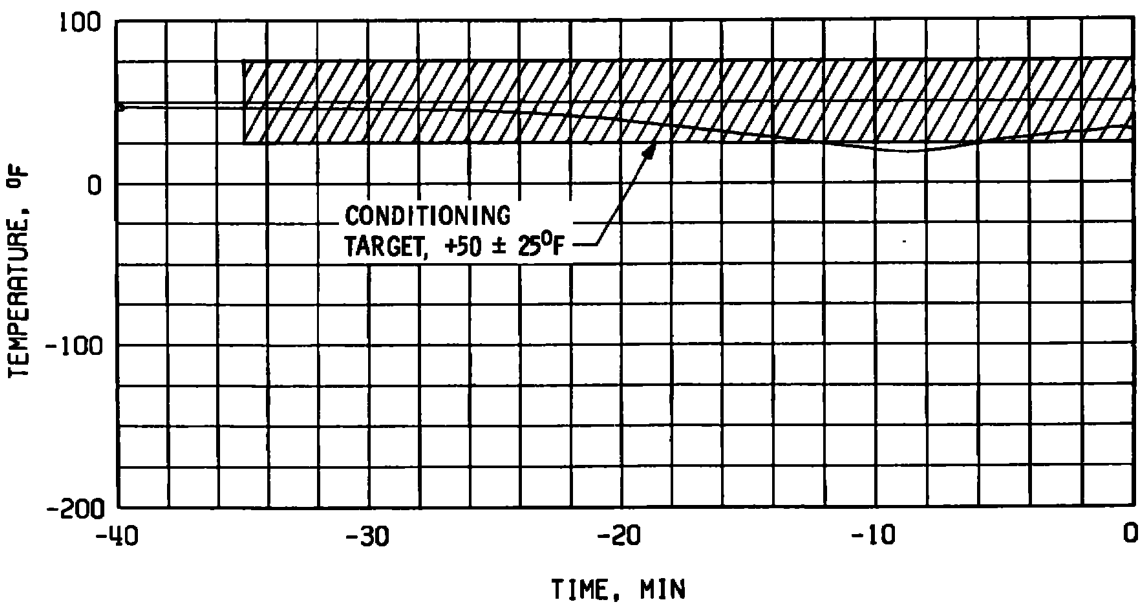


Fig. 10 Engine Ambient and Combustion Chamber Pressures, Firing 24A

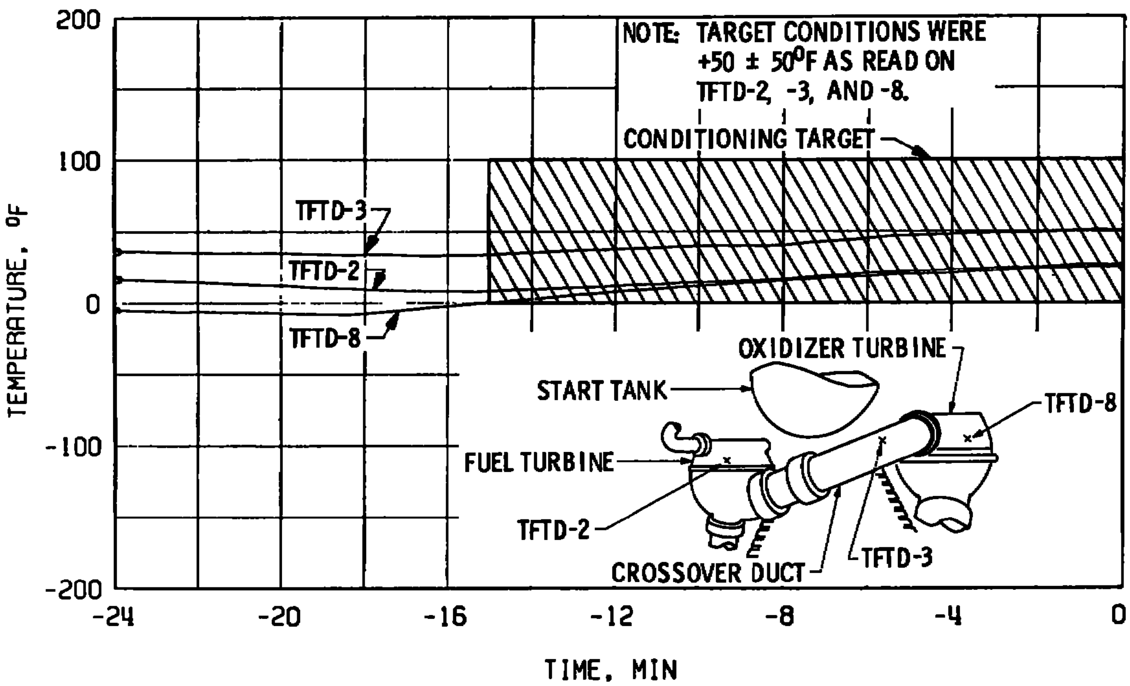


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

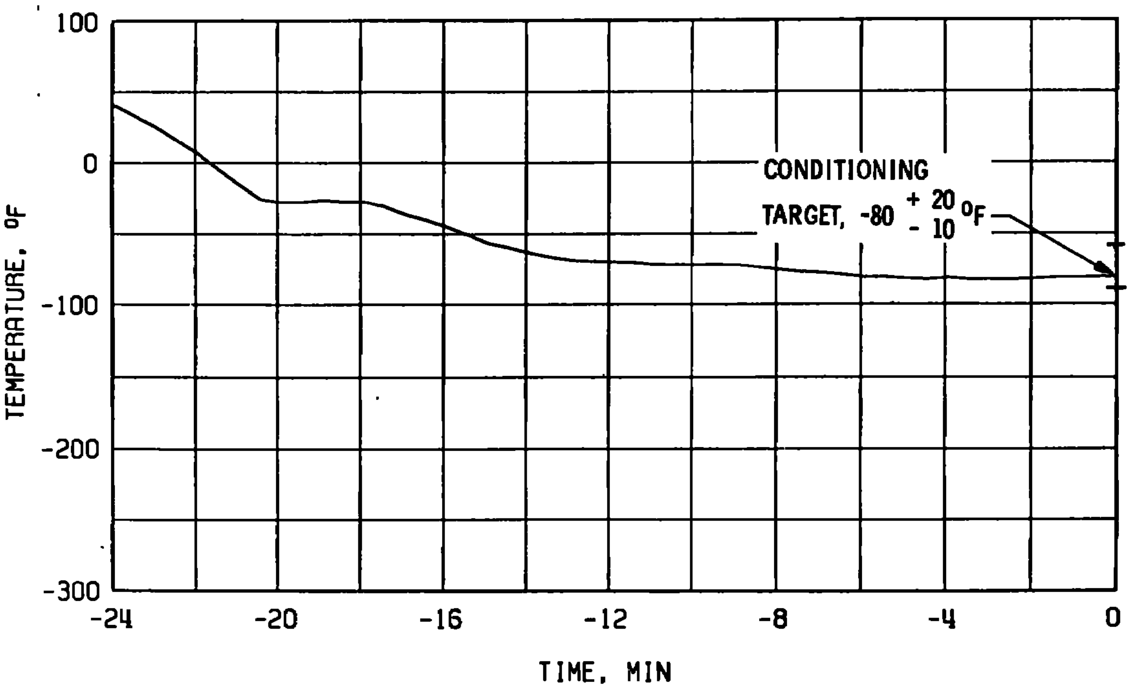


b. Start Tank Discharge Valve, TSTDVOC

Fig. 11 Thermal Conditioning History of Engine Components, Firing 24A



c. Crossover Duct, TFTD



d. Thrust Chamber Throat, TTC-IP

Fig. 11 Concluded

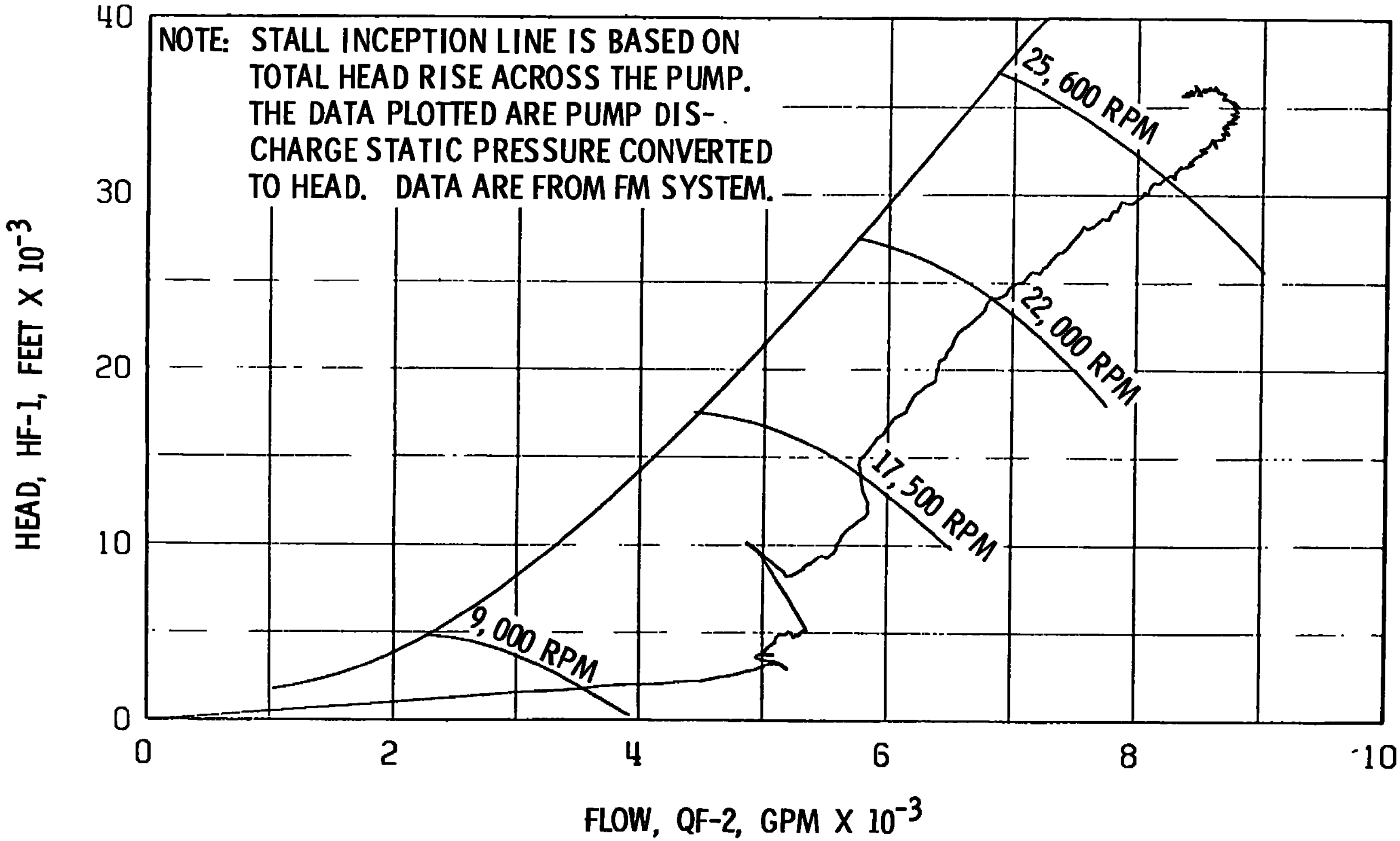


Fig. 12 Fuel Pump Start Transient Performance, Firing 24A

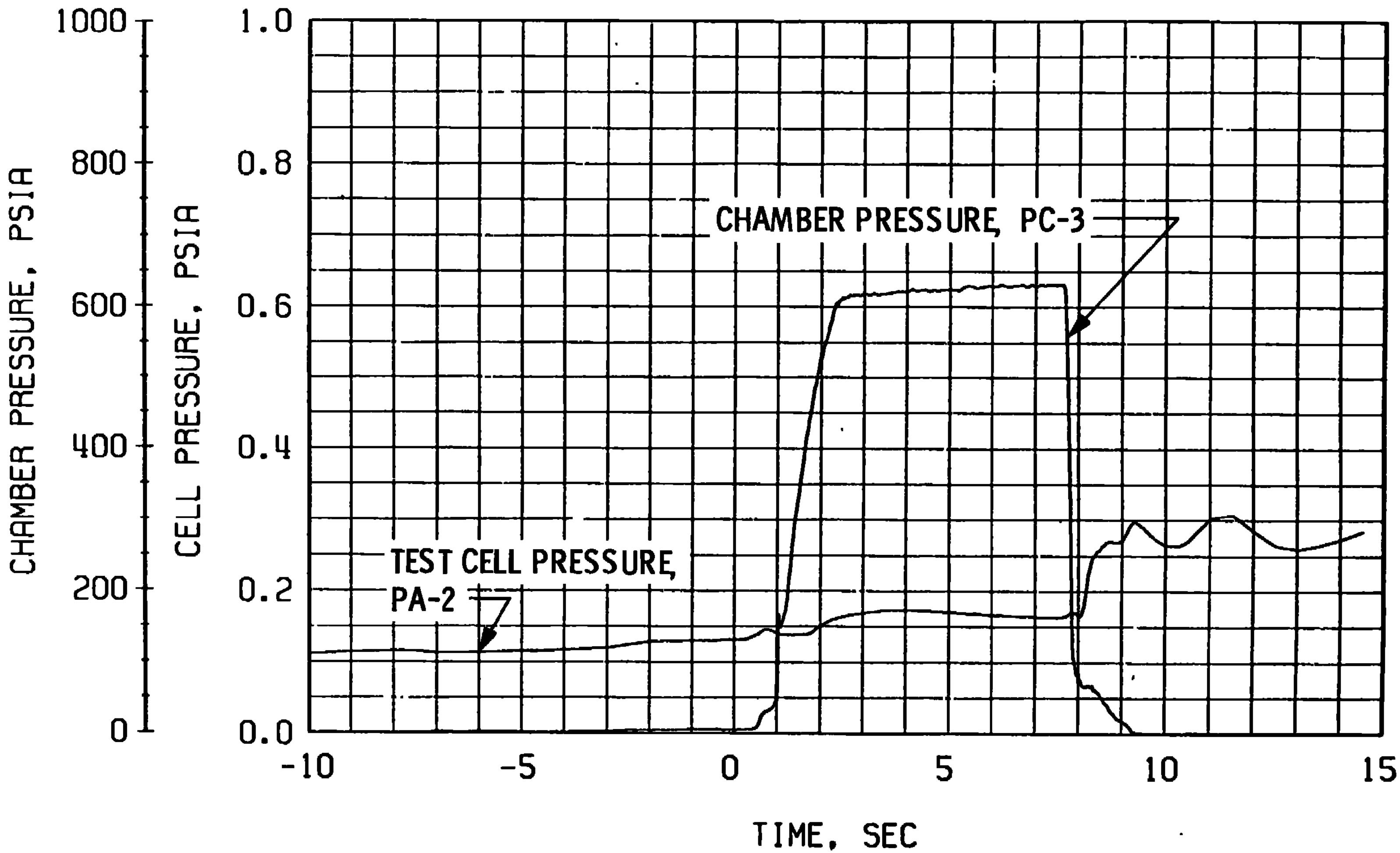
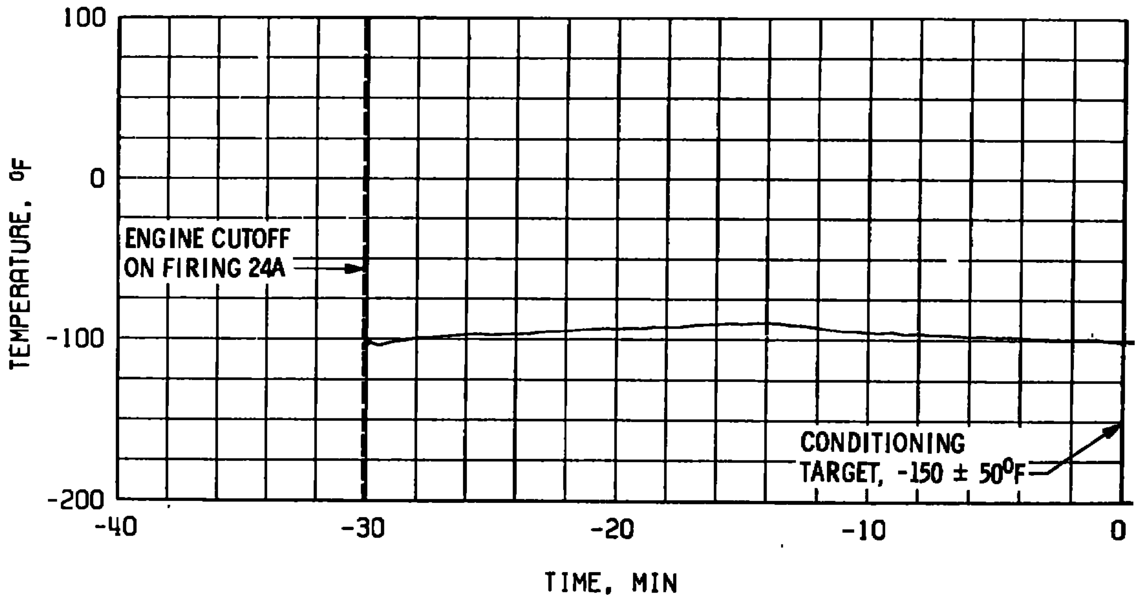
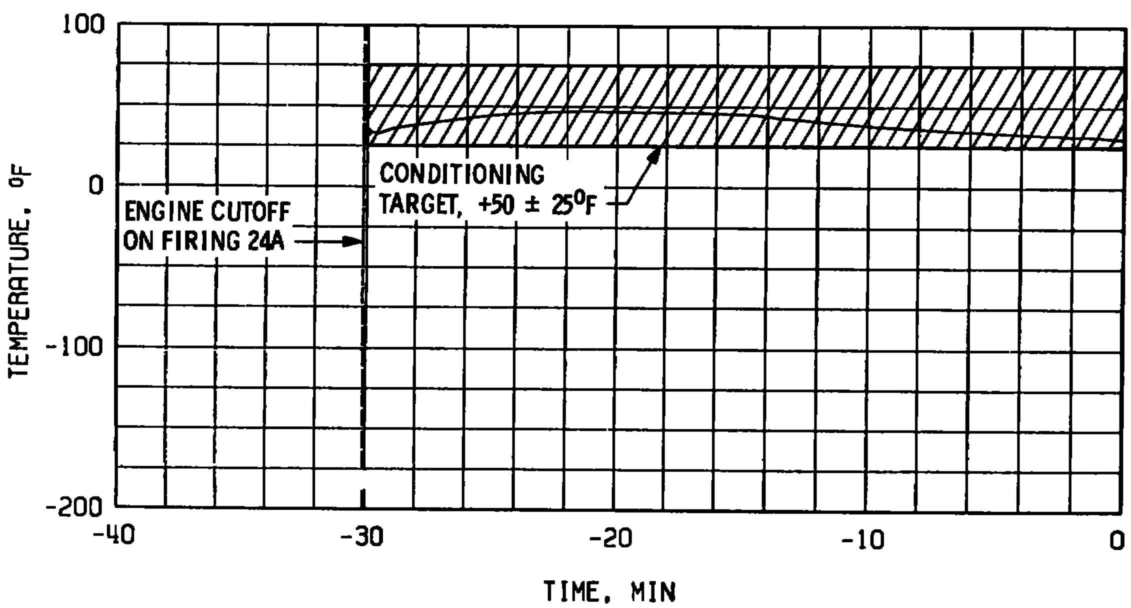


Fig. 13 Engine Ambient and Combustion Chamber Pressures, Firing 24B

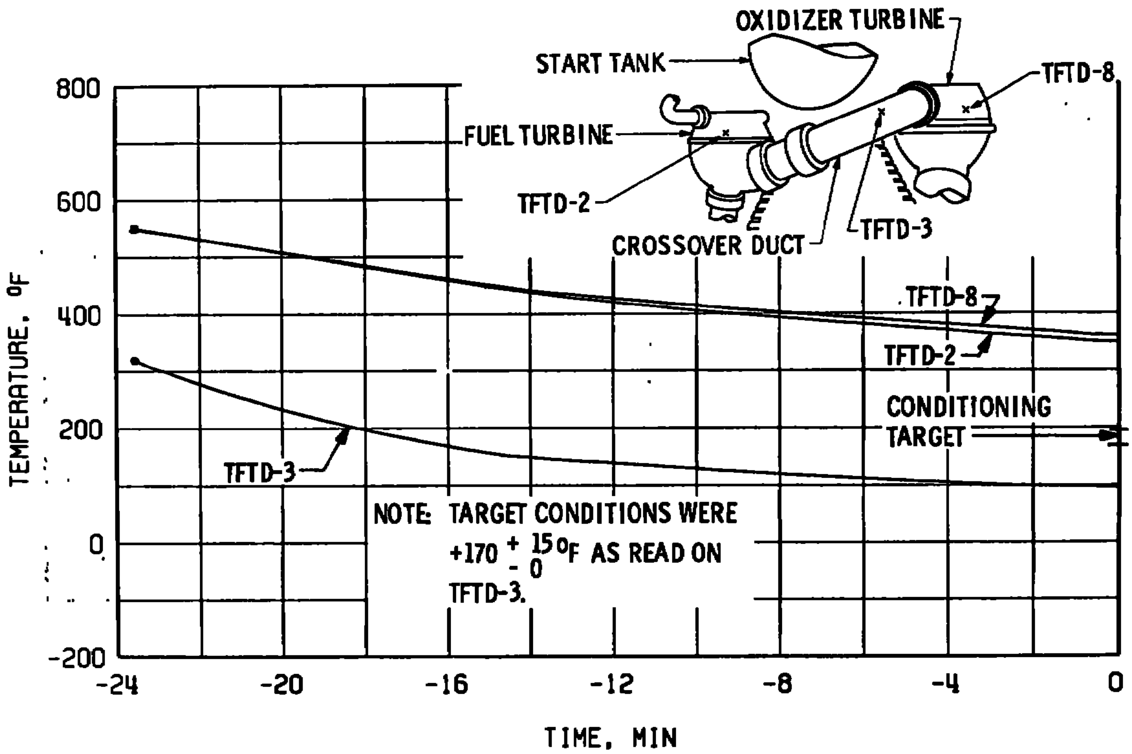


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

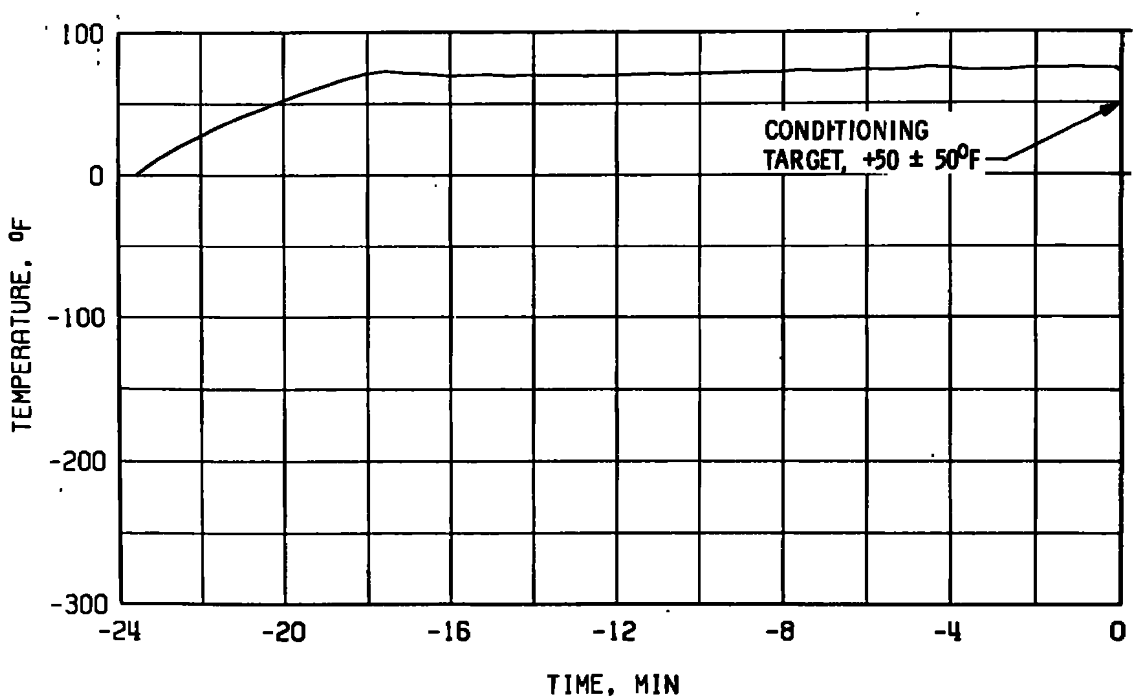


b. Start Tank Discharge Valve, TSTDVOC

Fig. 14 Thermal Conditioning History of Engine Components, Firing 24B

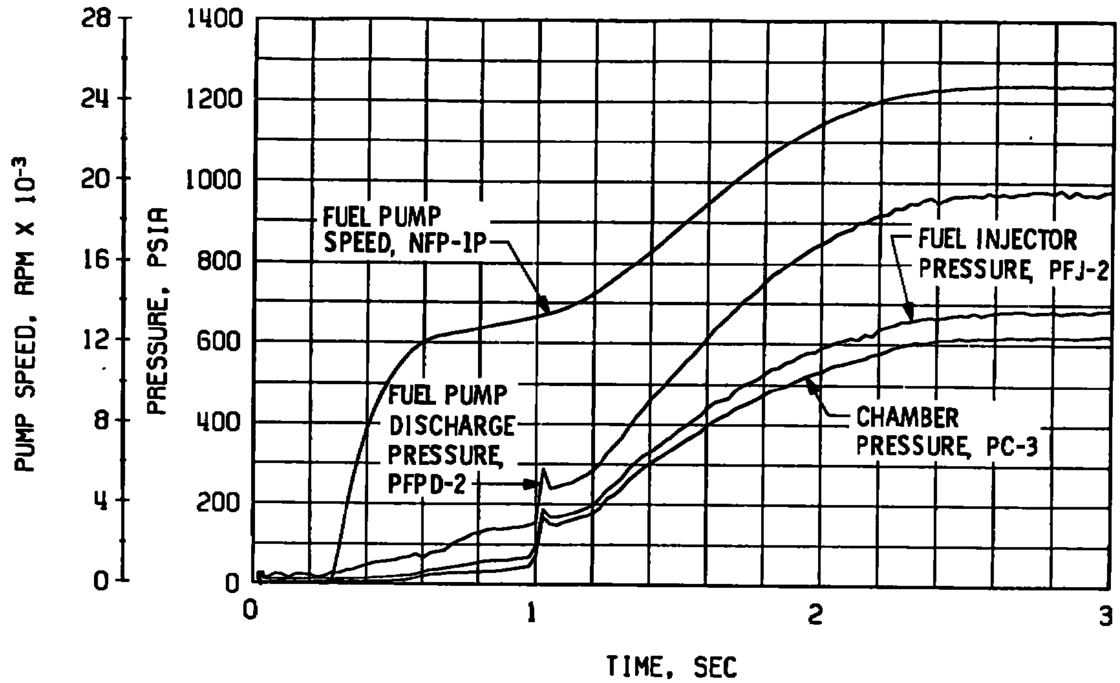


c. Crossover Duct, TFTD

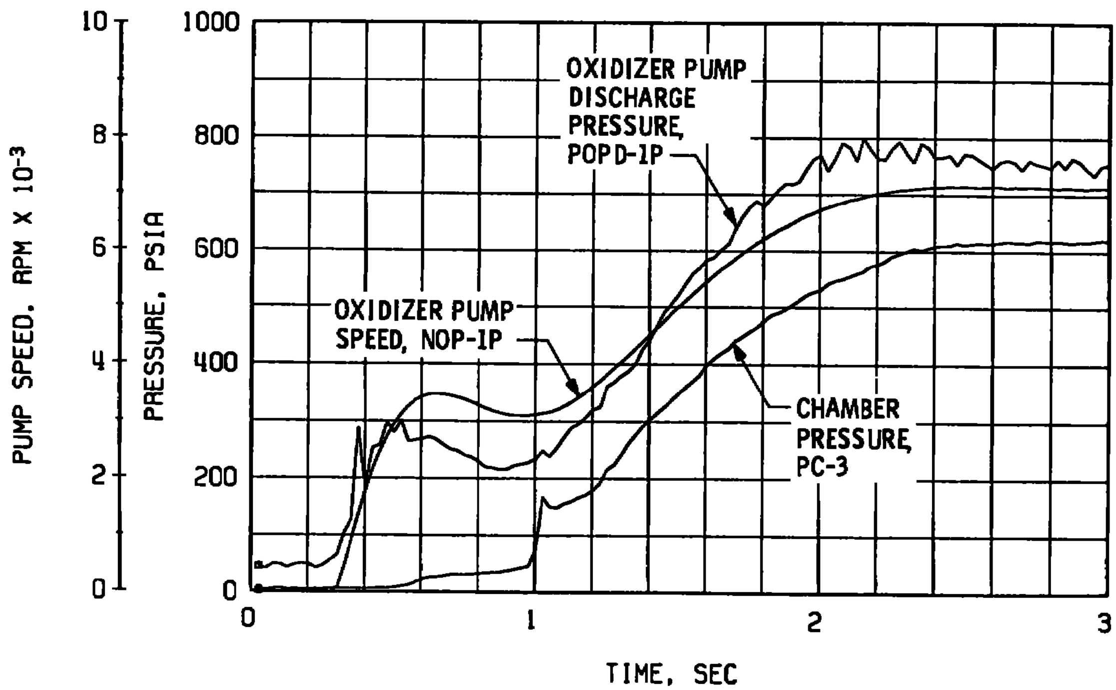


d. Thrust Chamber Throat, TTC-1P

Fig. 14 Concluded

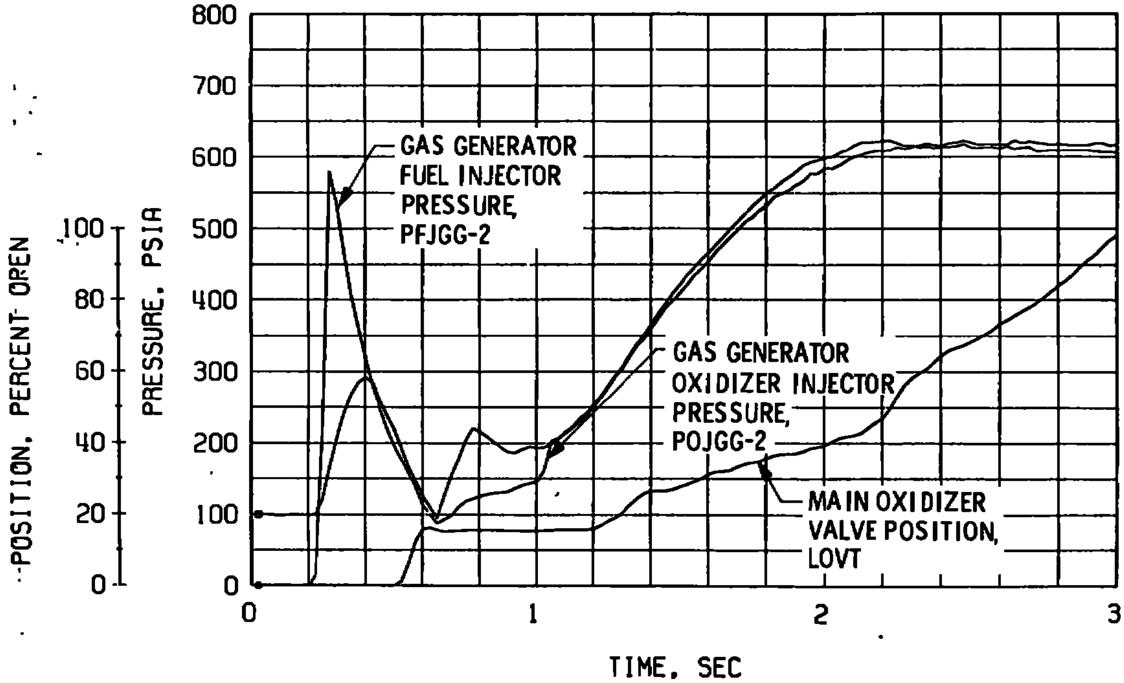


a. Thrust Chamber Fuel System, Start

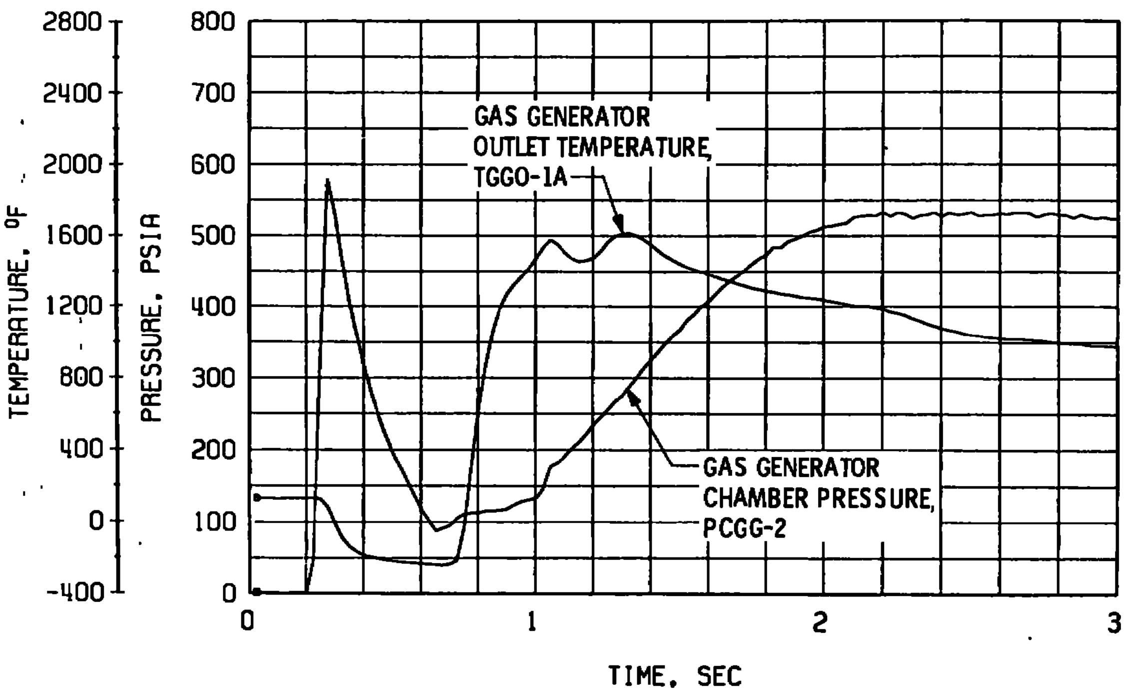


b. Thrust Chamber Oxidizer System, Start

Fig. 15 Engine Transient Operation, Firing 24B

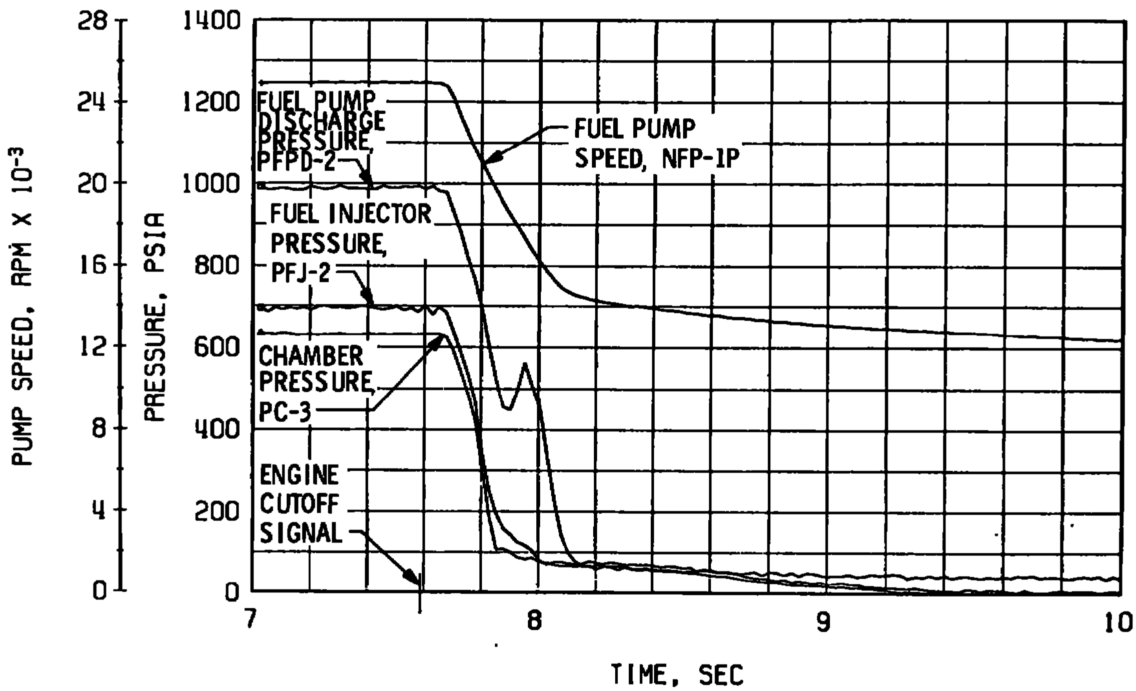


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

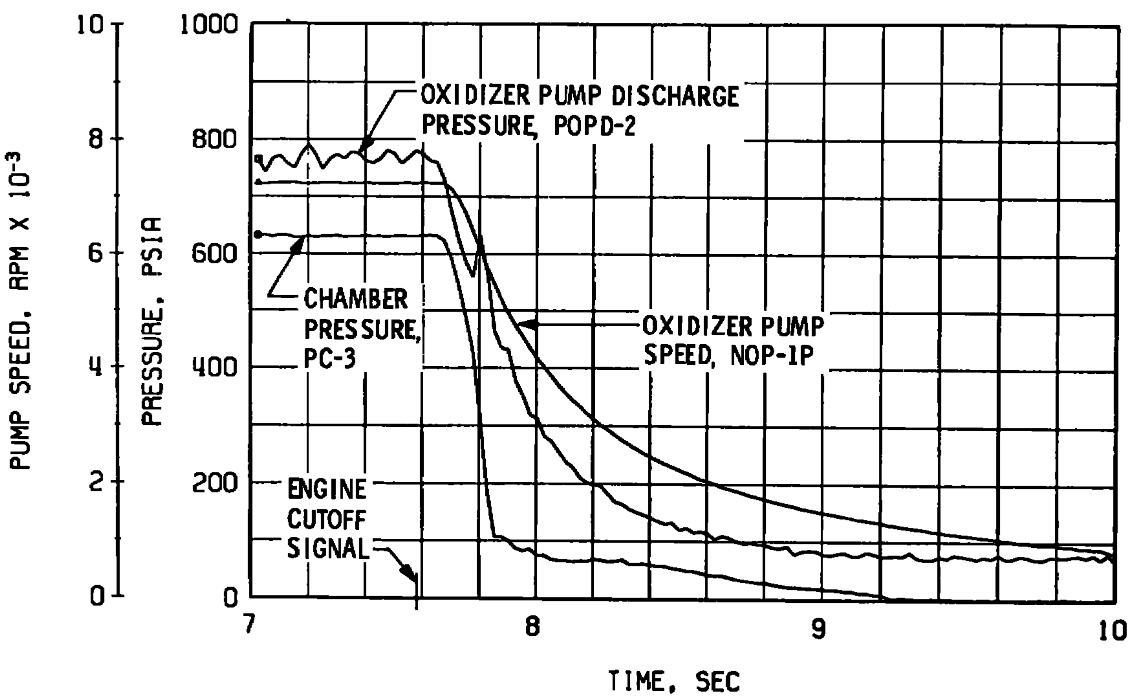


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 15 Continued

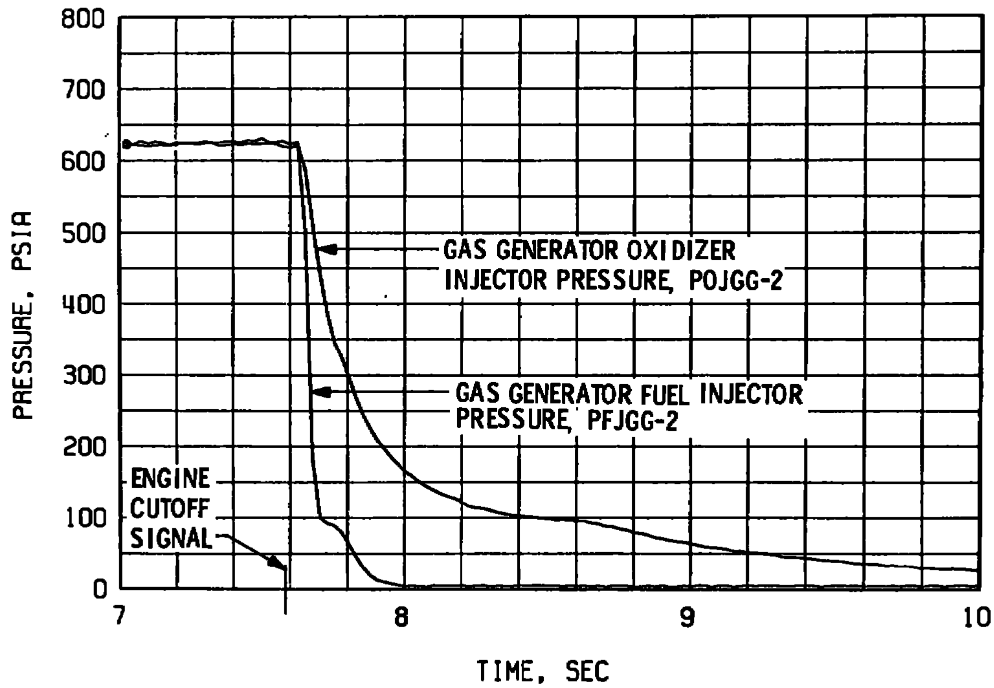


e. Thrust Chamber Fuel System, Shutdown

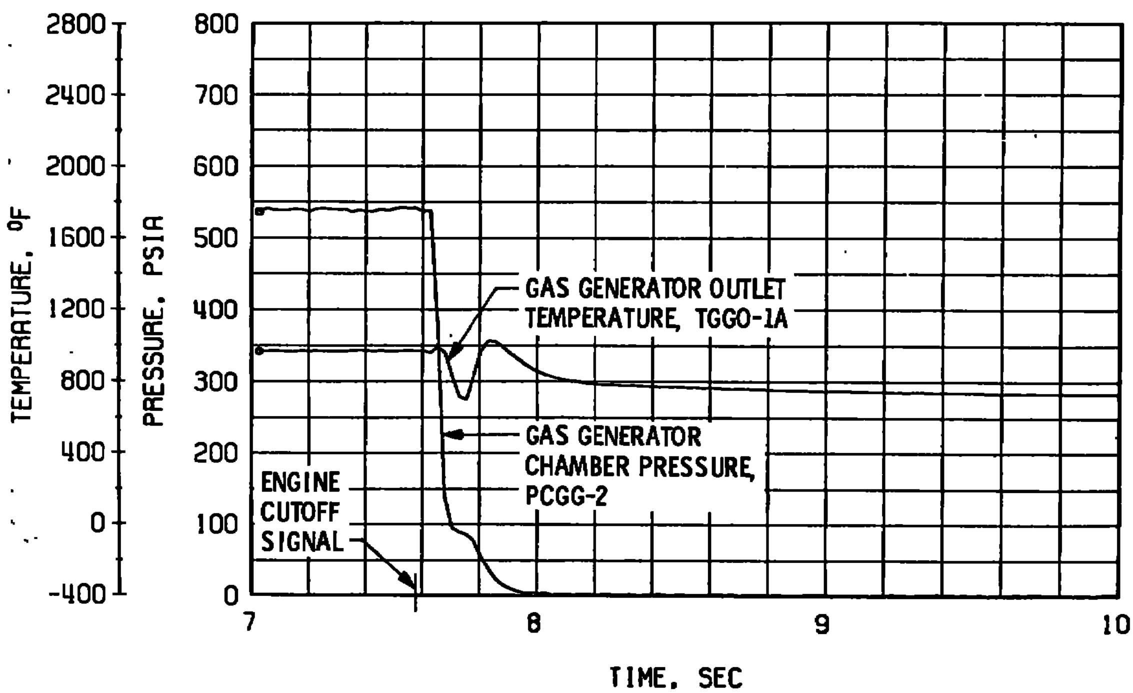


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 15 Continued



g. Gas Generator Injector Pressure, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 15 Concluded

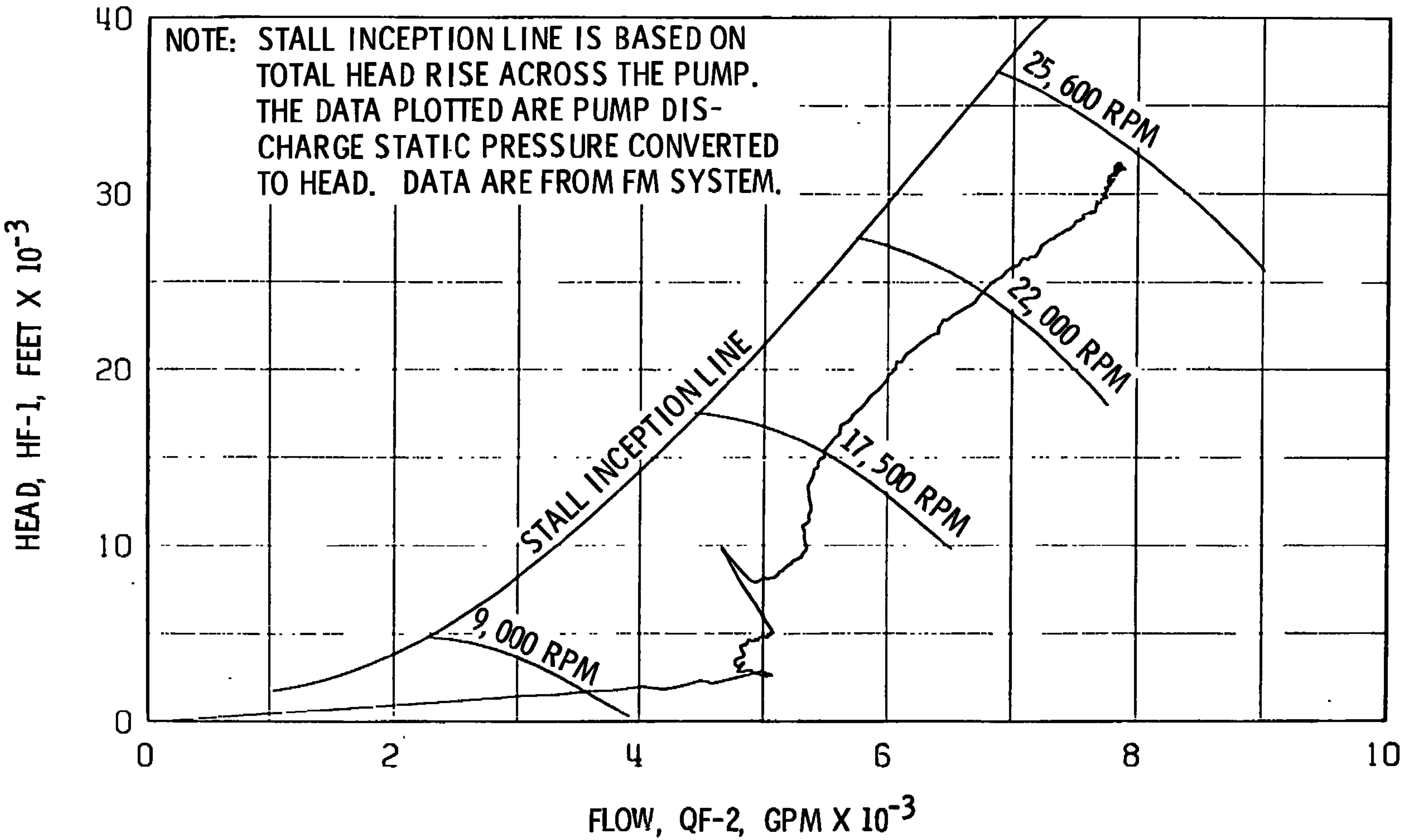
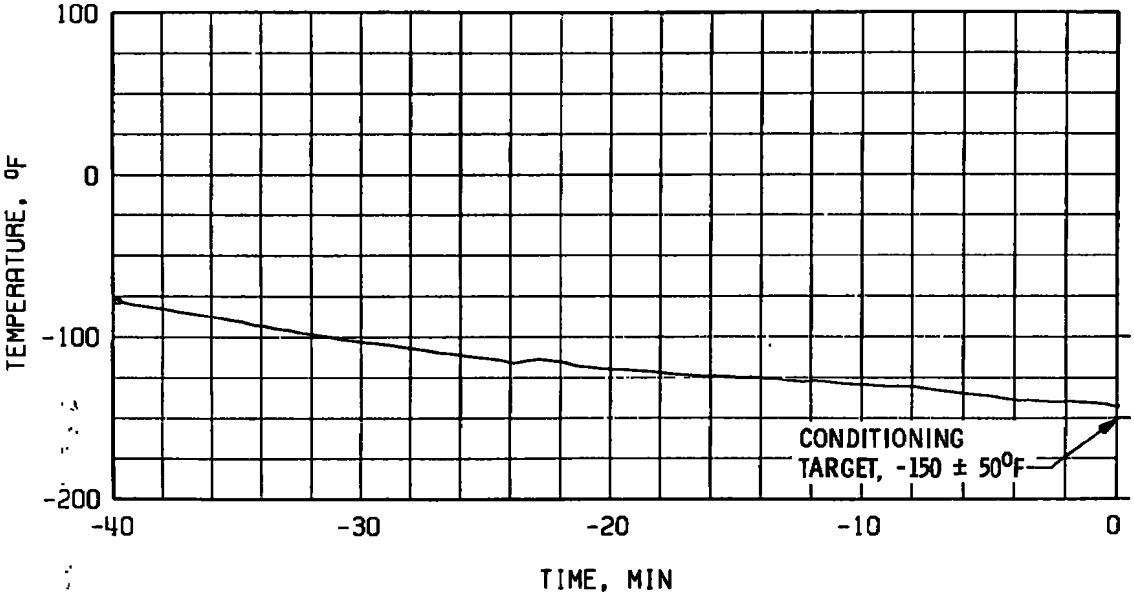
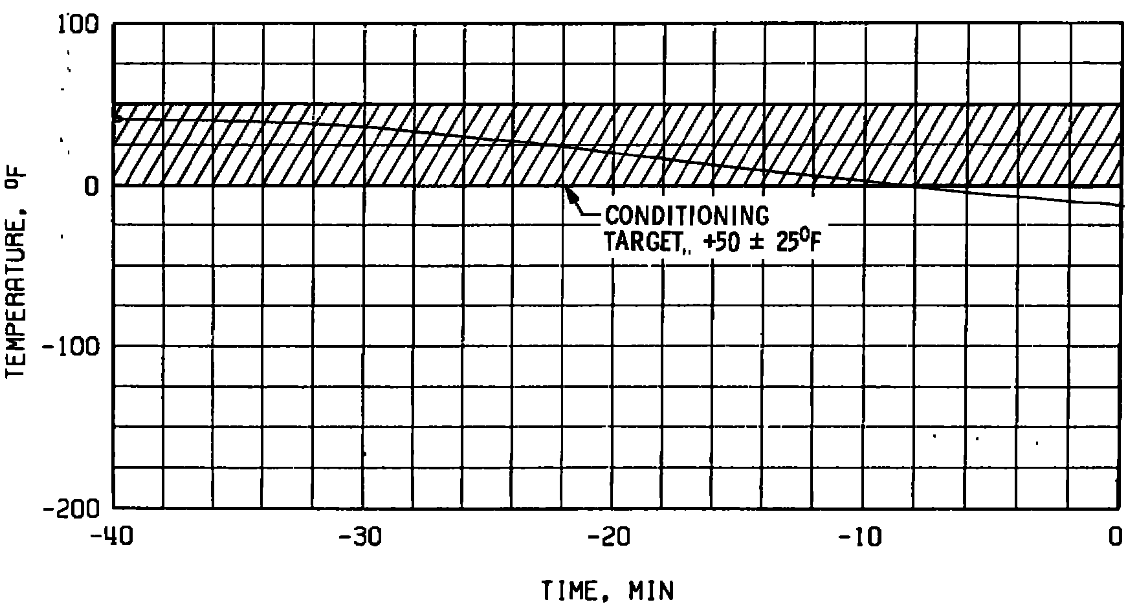


Fig. 16 Fuel Pump Start Transient Performance, Firing 24B

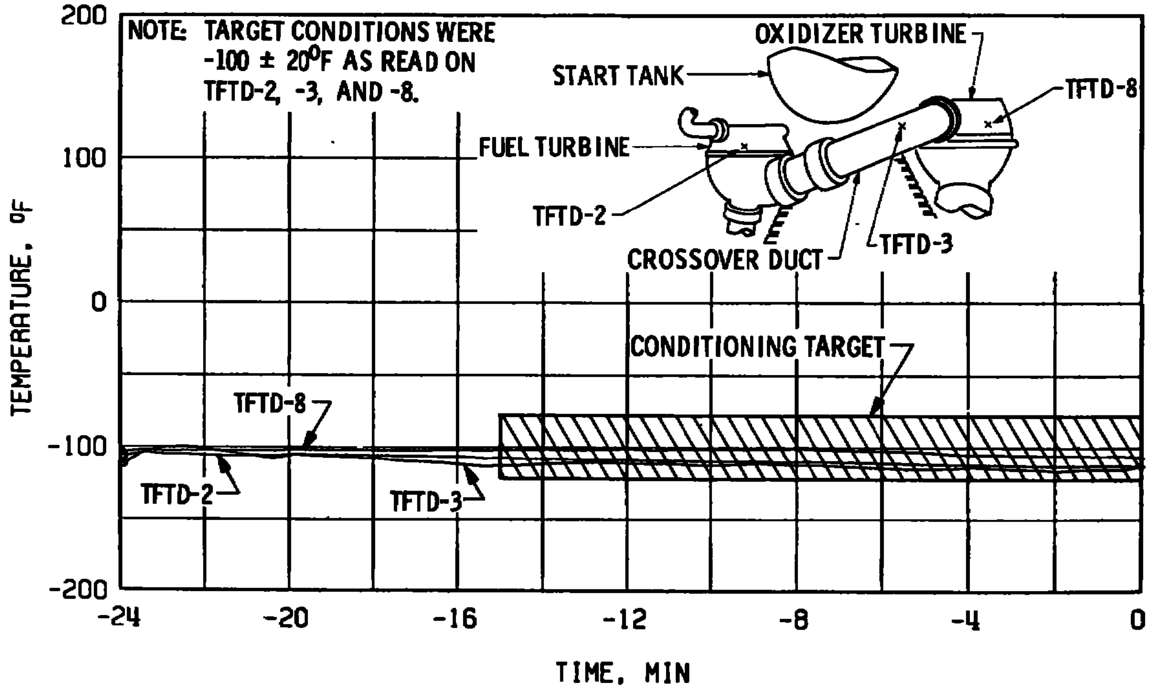


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

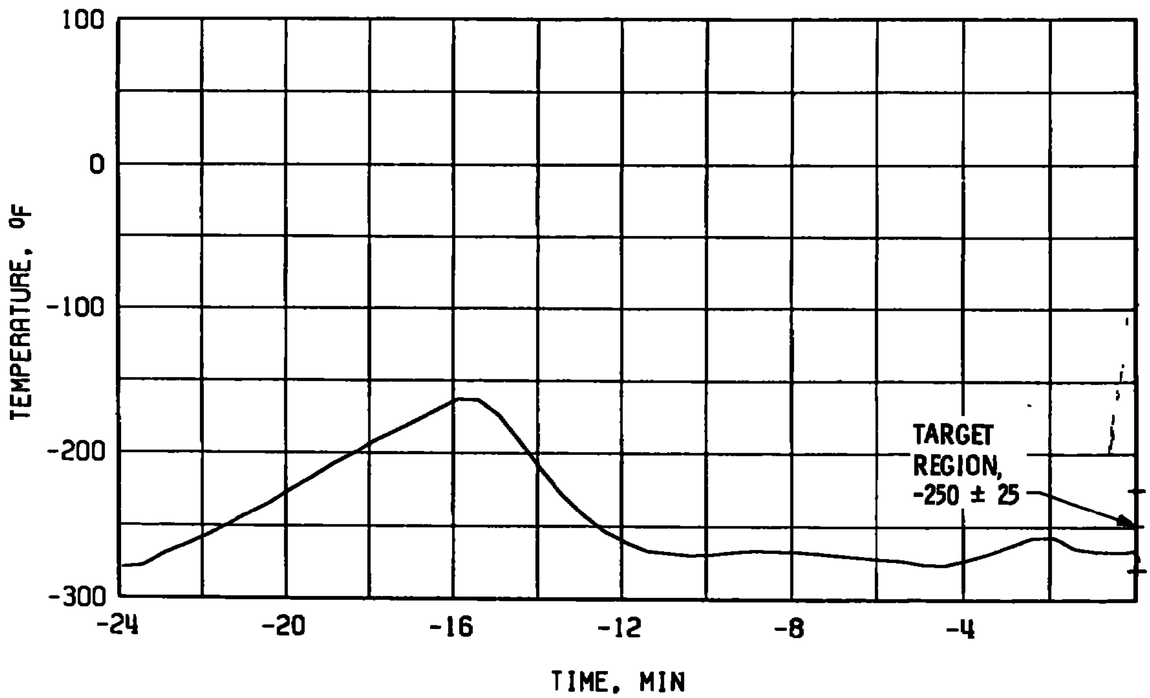


b. Start Tank Discharge Valve, TSTDVOC

Fig. 17 Thermal Conditioning History of Engine Components, Firing 25A



c. Crossover Duct, TFTD



d. Thrust Chamber Throat, TTC-1P

Fig. 17 Concluded

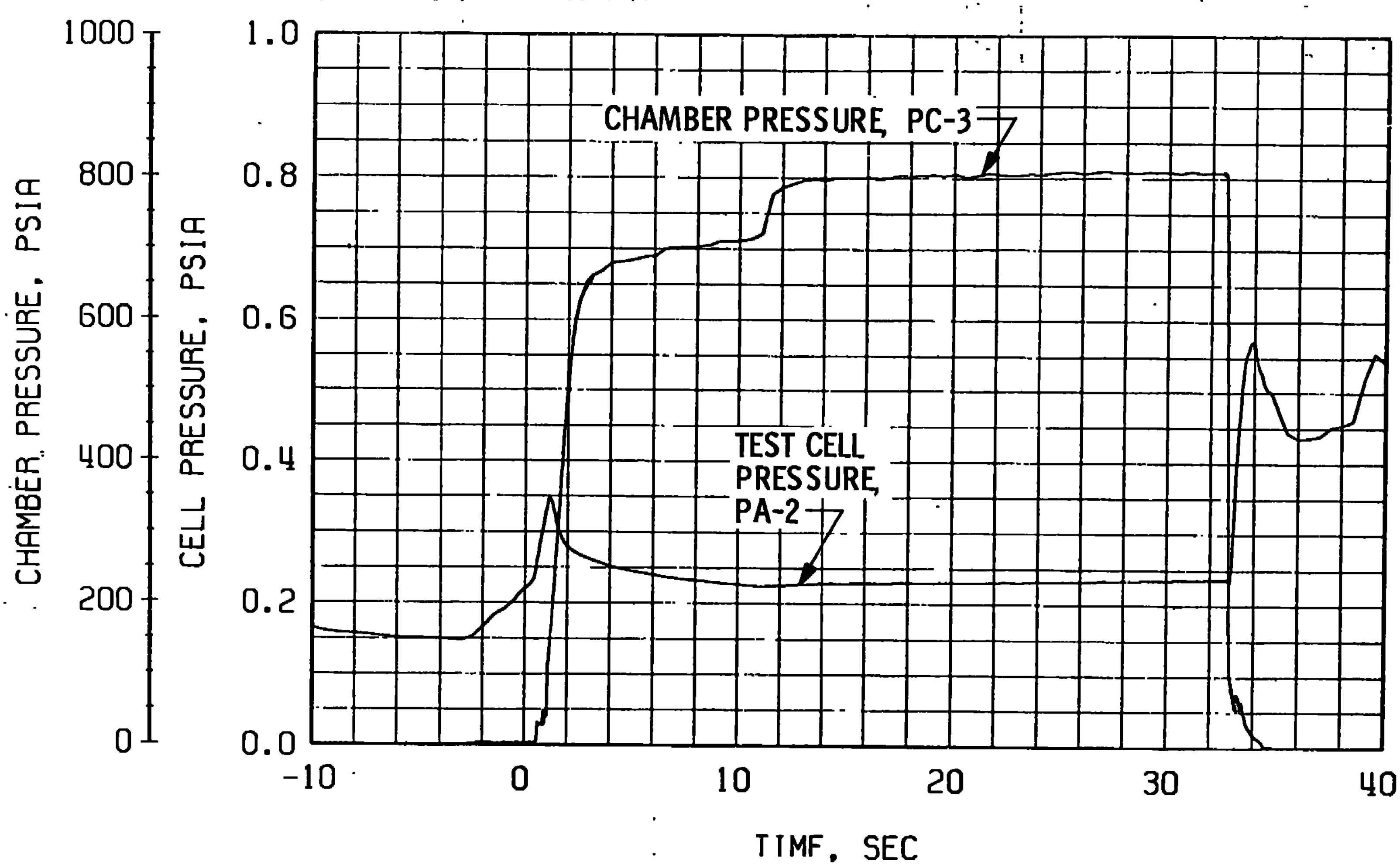
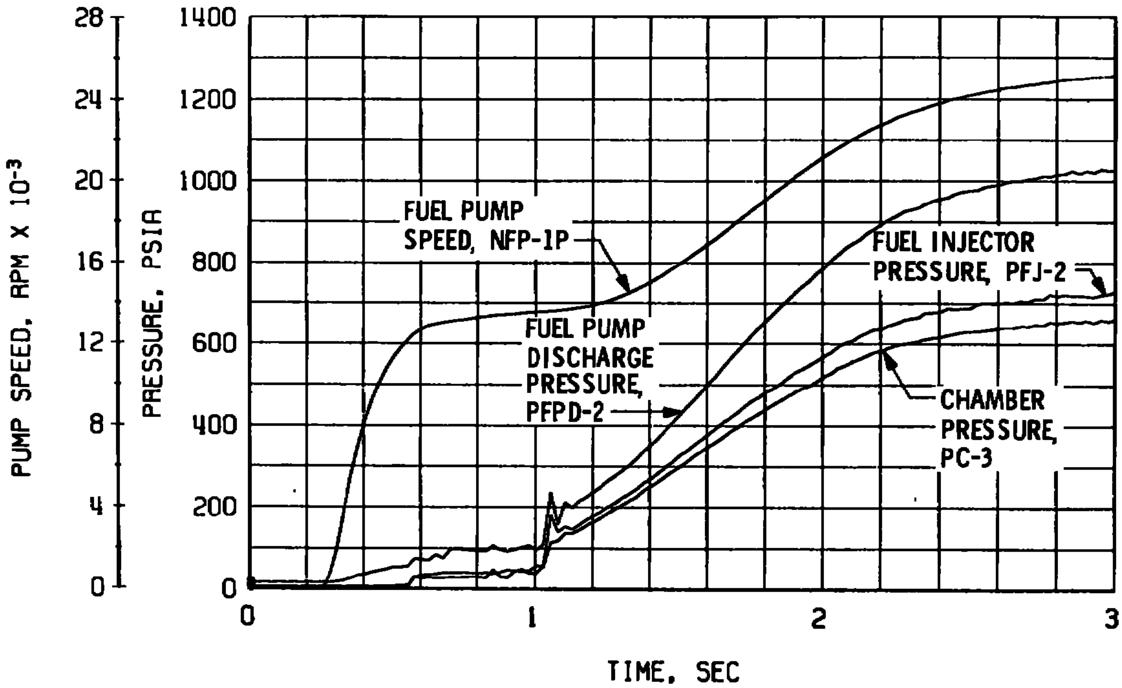
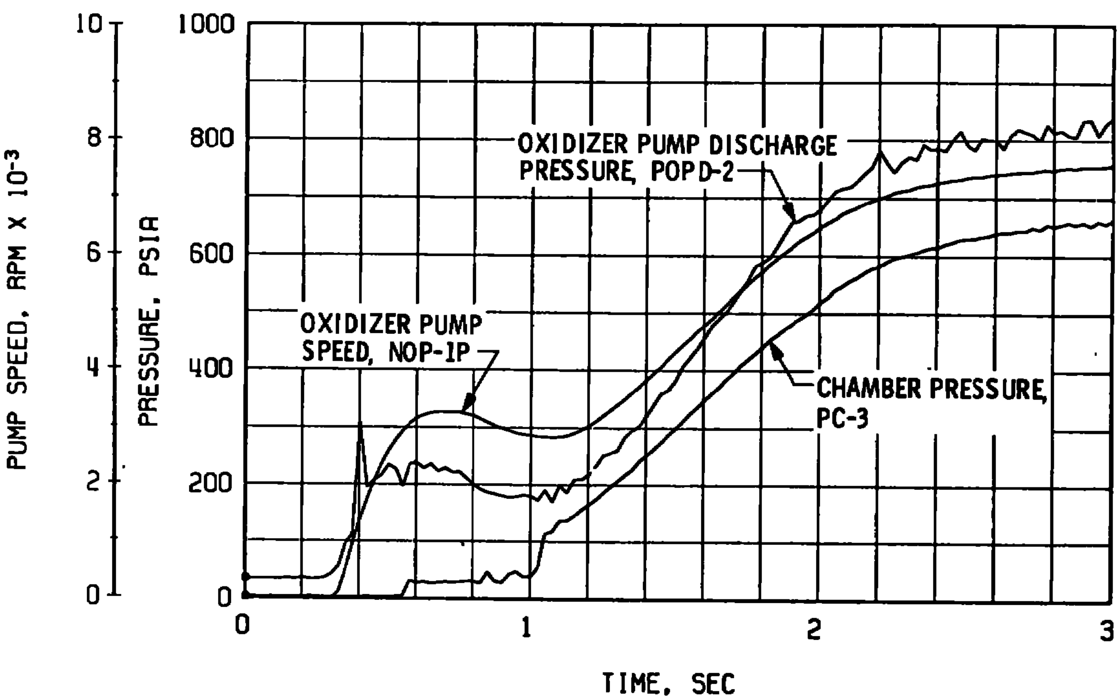


Fig. 18 Engine Ambient and Conbustion Chamber Pressures, Firing 25A

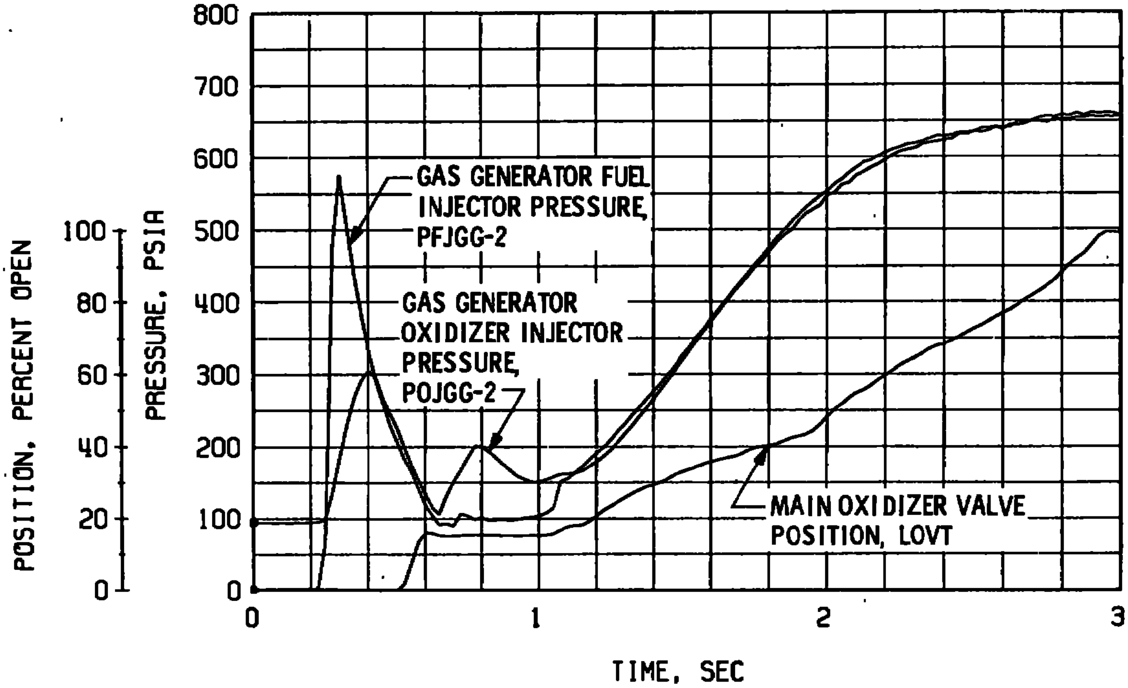


a. Thrust Chamber Fuel System, Start

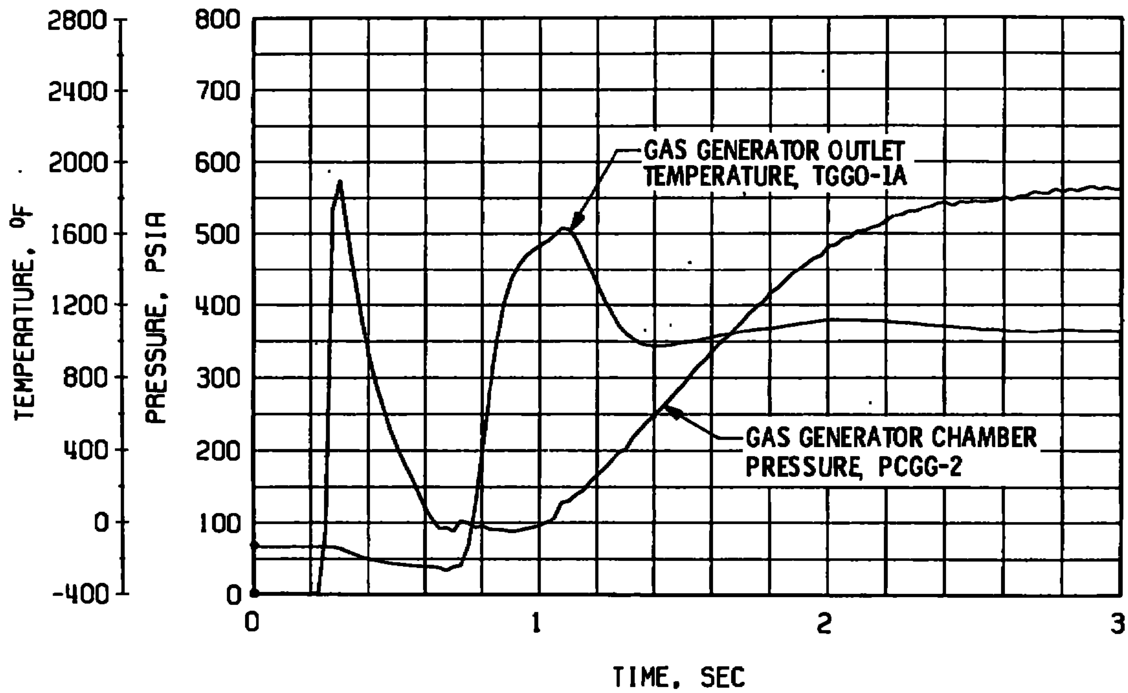


b. Thrust Chamber Oxidizer System, Start

Fig. 19 Engine Transient Operation, Firing 25A

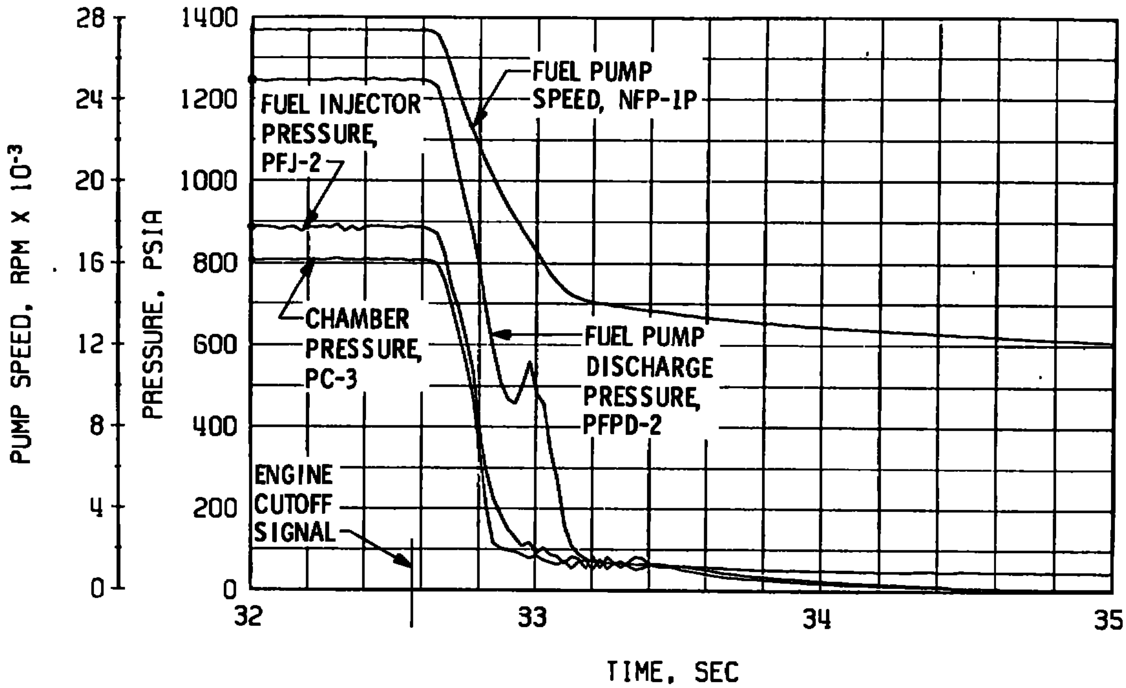


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

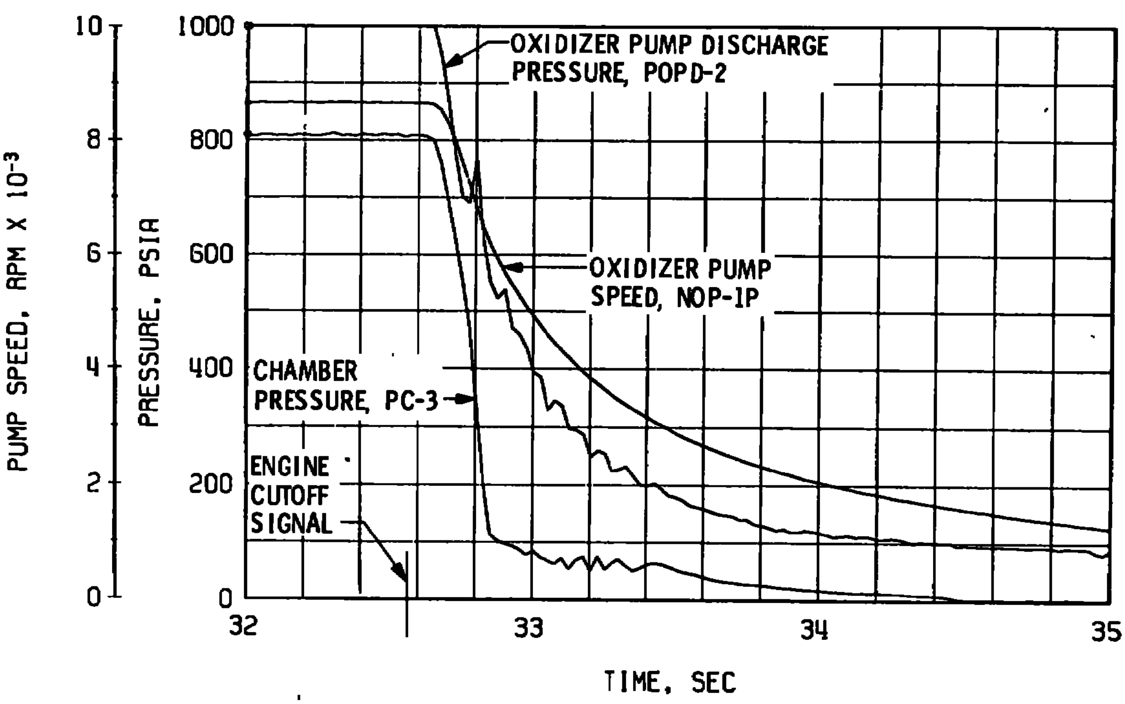


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 19 Continued

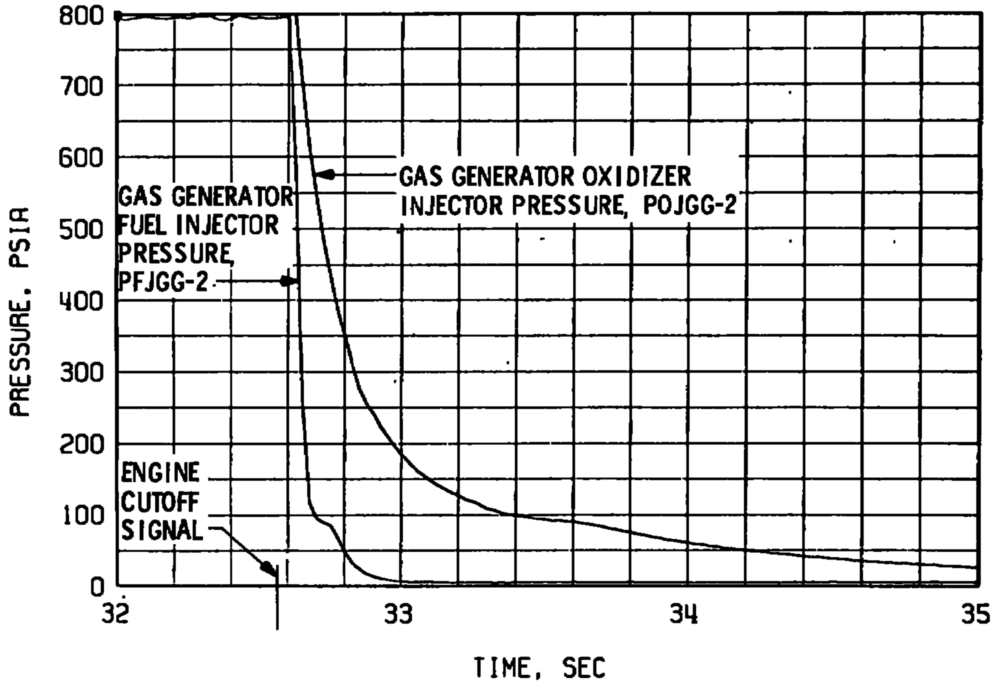


e. Thrust Chamber Fuel System, Shutdown

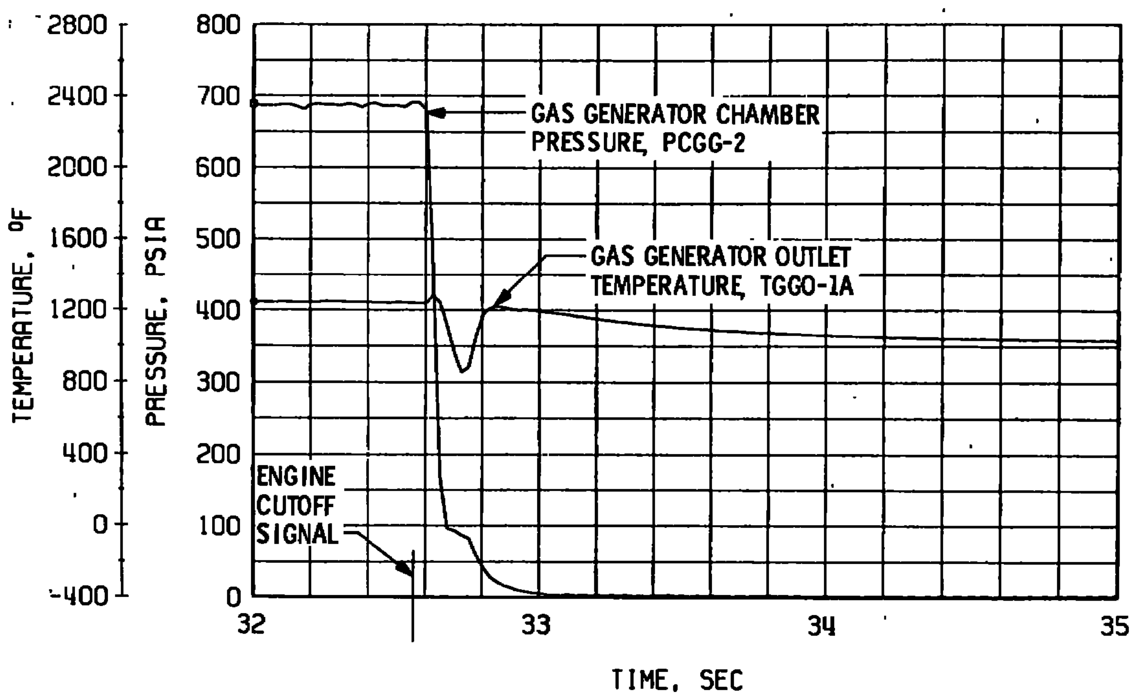


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 19 Continued



g. Gas Generator Injector Pressure, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 19 Concluded

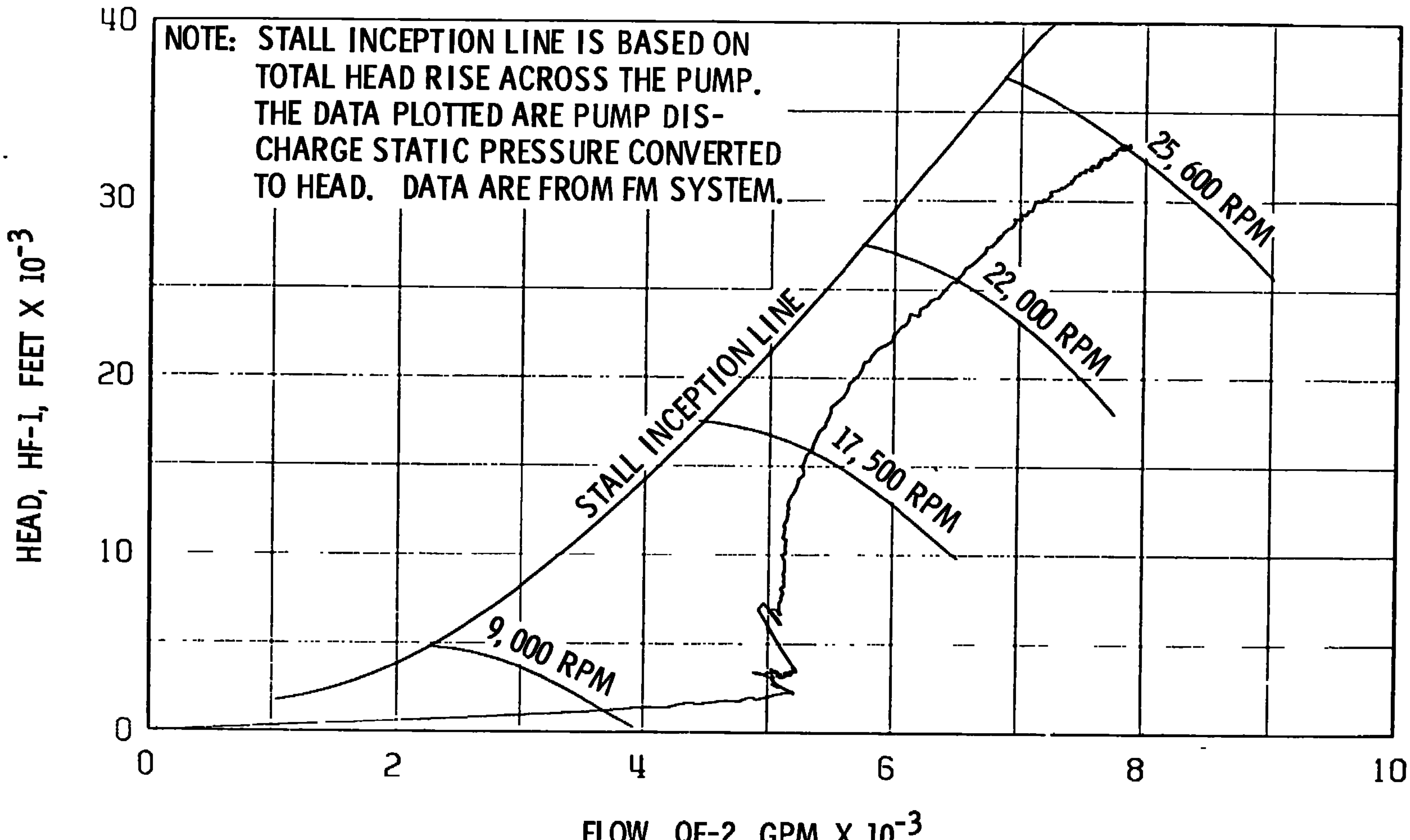


Fig. 20 Fuel Pump Start Transient Performance, Firing 25A

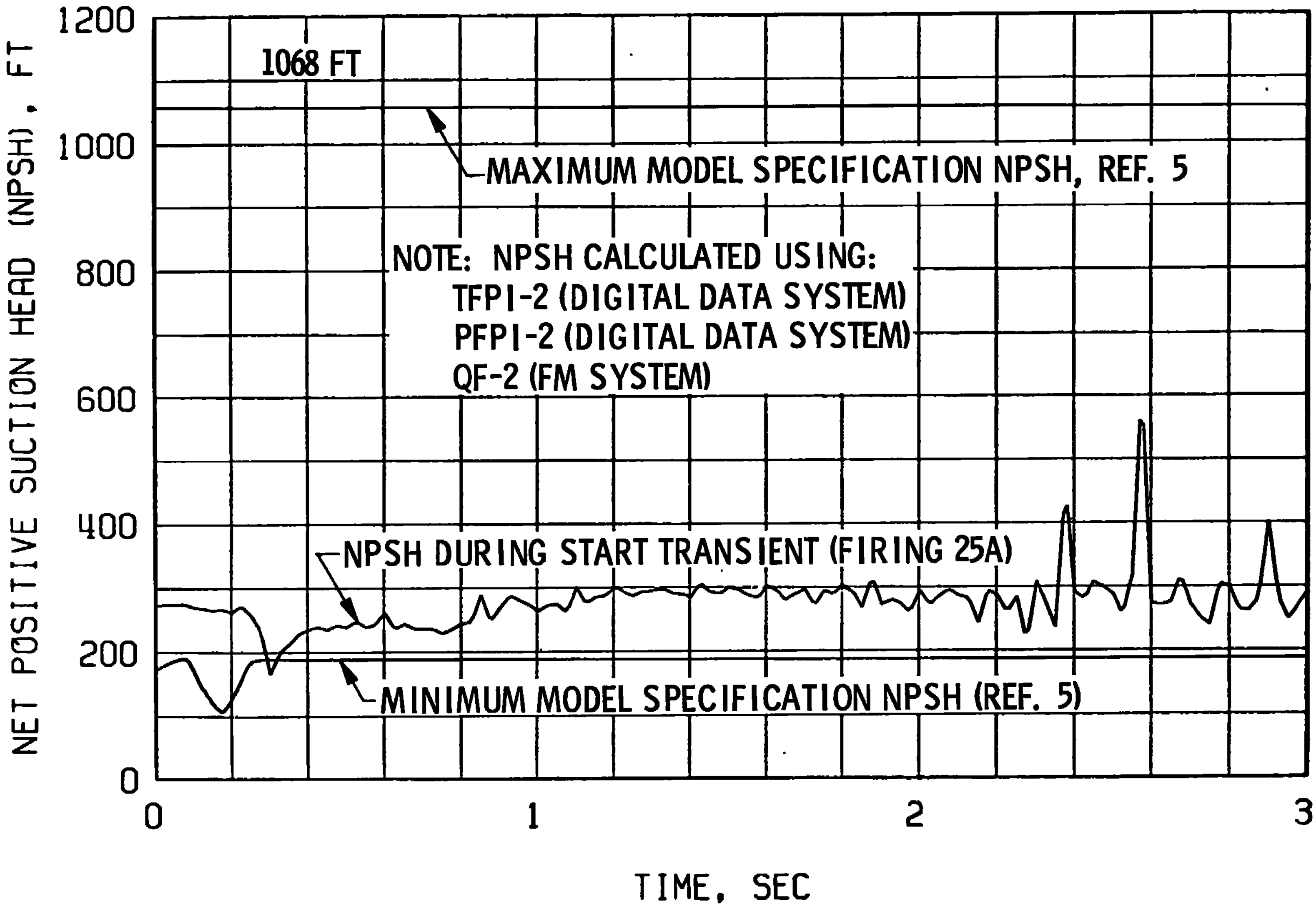


Fig. 21 Fuel Pump Net Positive Suction Head during Start Transient, Firing 25A

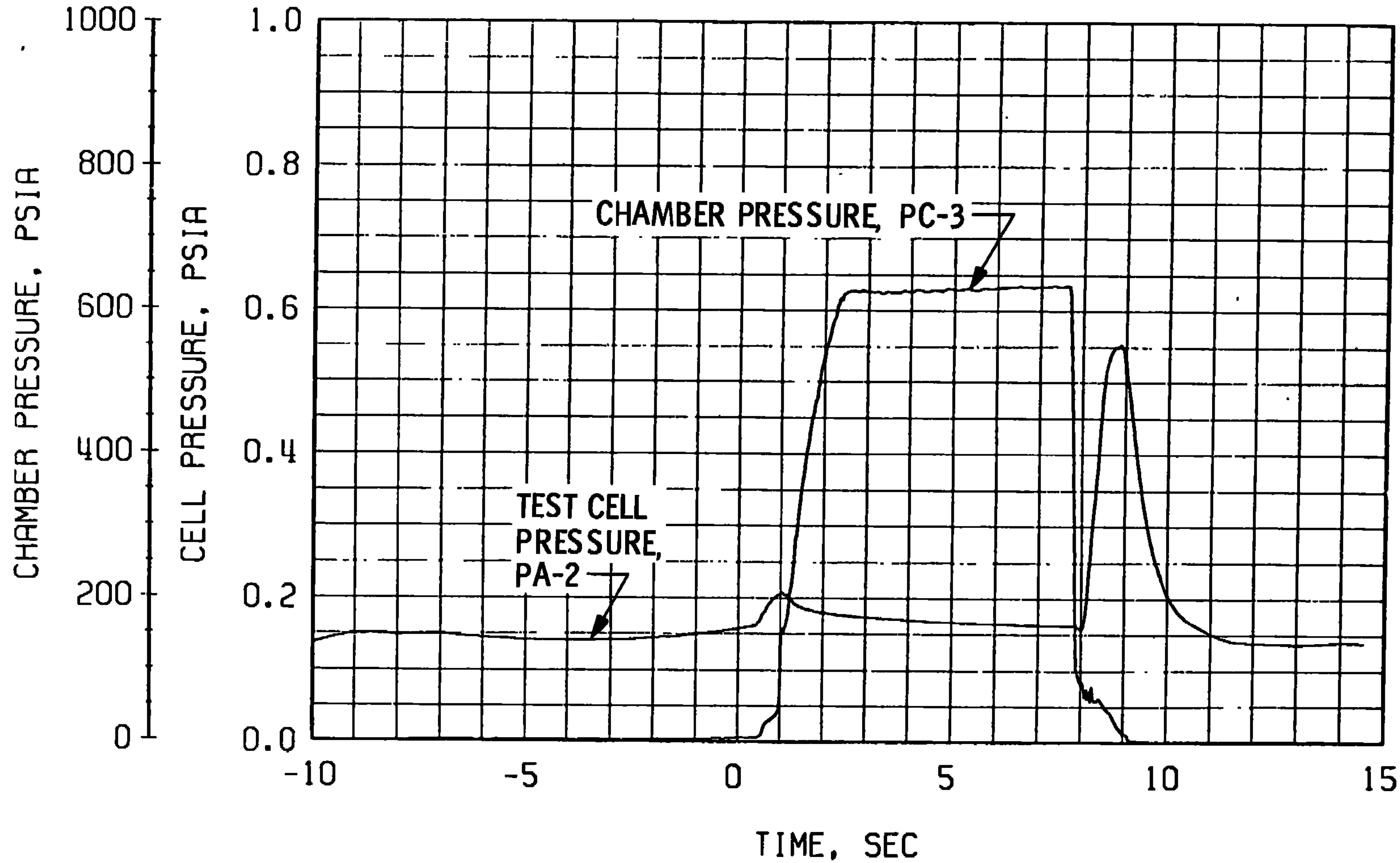
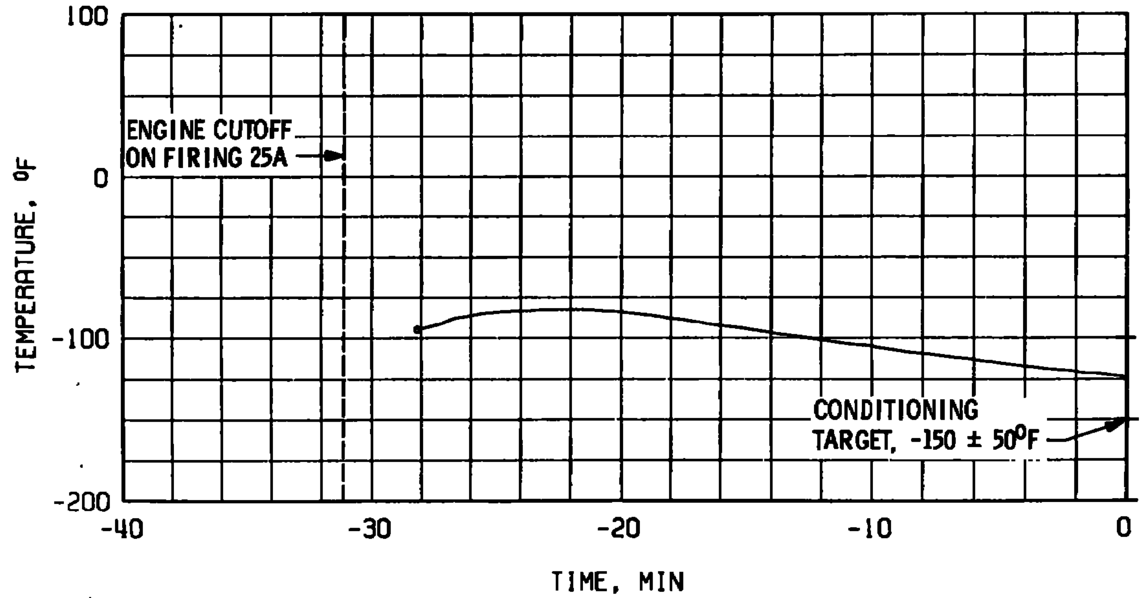
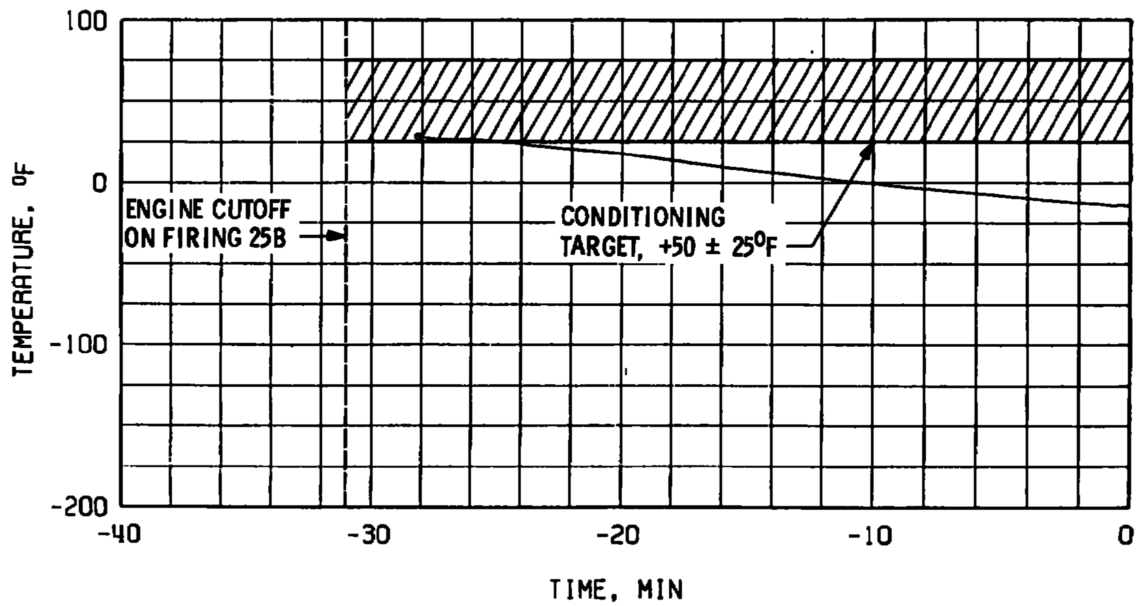


Fig. 22 Engine Ambient and Combustion Chamber Pressures, Firing 25B

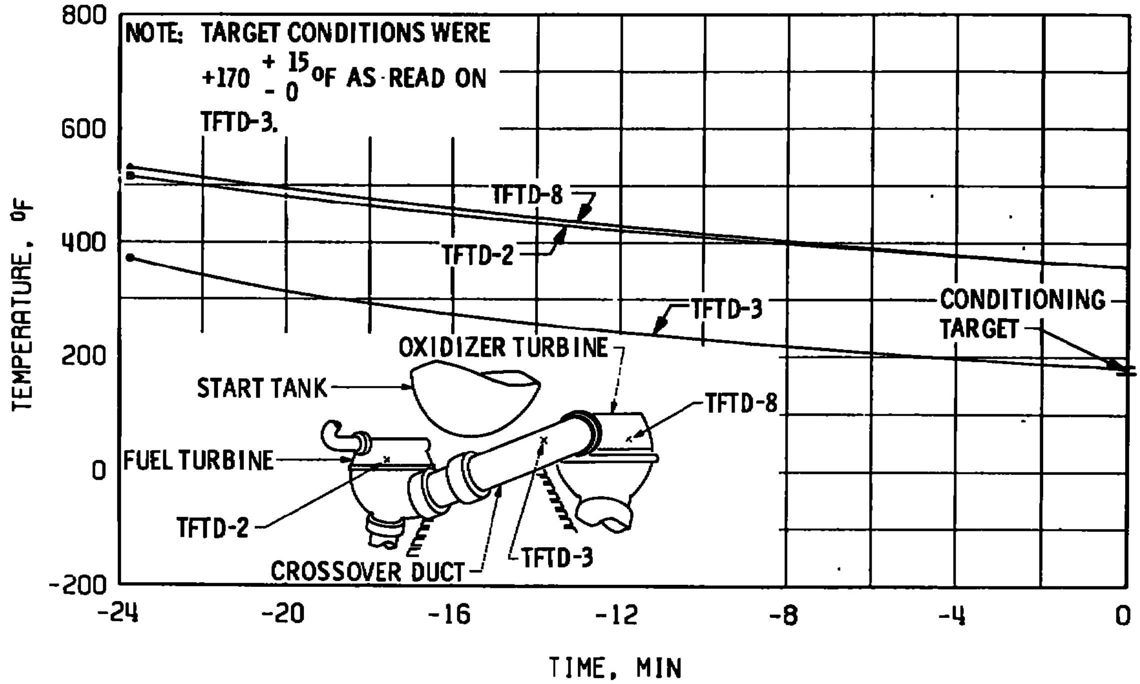


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

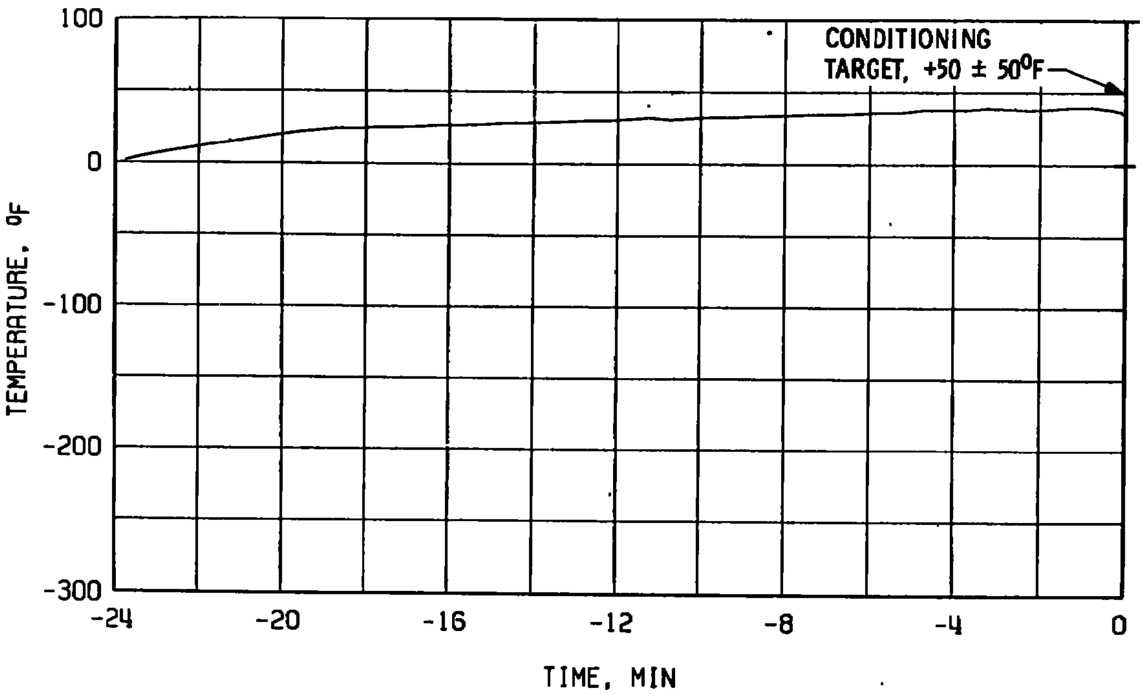


b. Start Tank Discharge Valve, TSTDVOC

Fig. 23 Thermal Conditioning History of Engine Components, Firing 25B

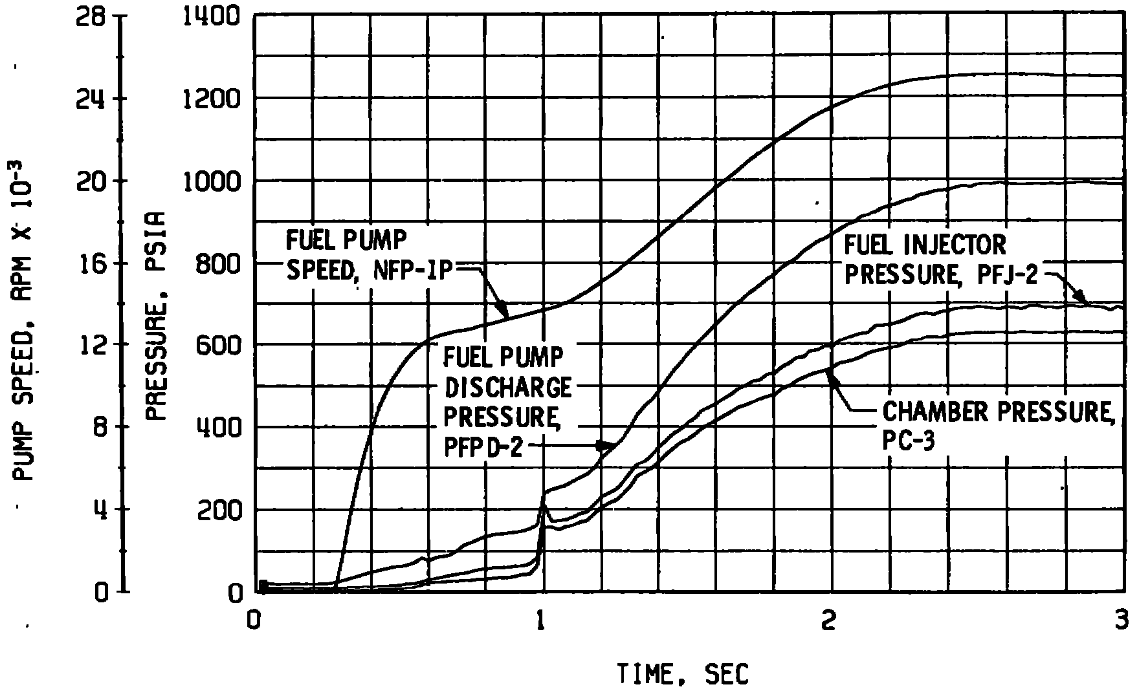


c. Crossover Duct, TFTD

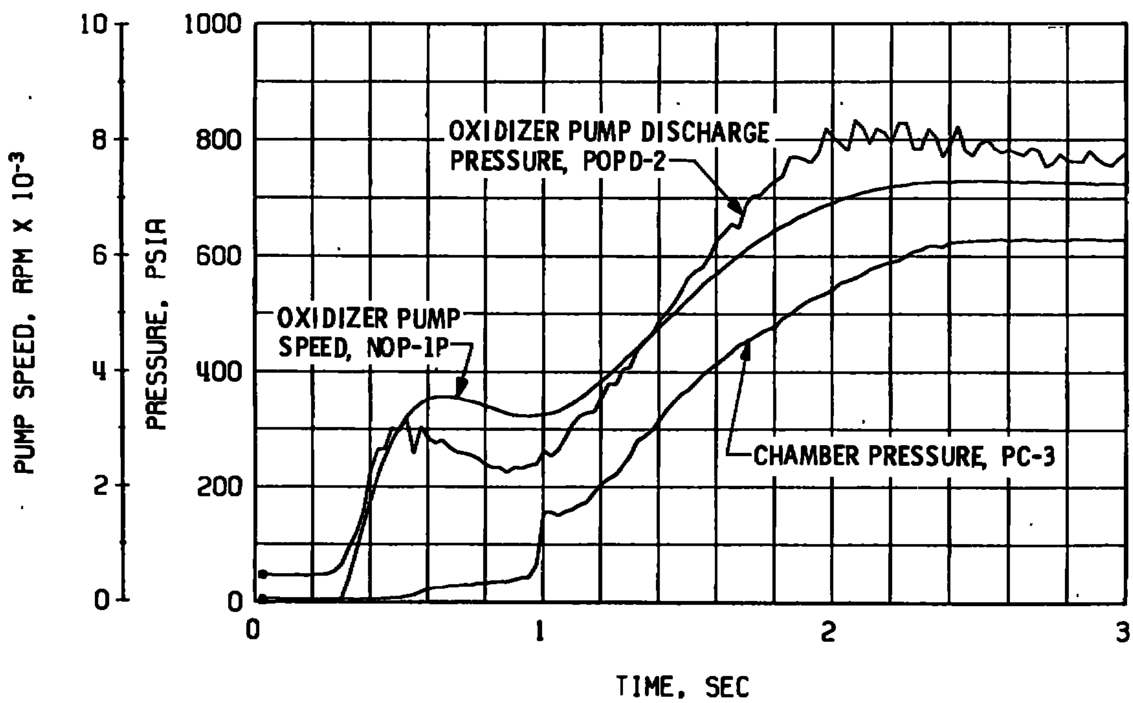


d. Thrust Chamber Throat, TTC-1P

Fig. 23 Concluded

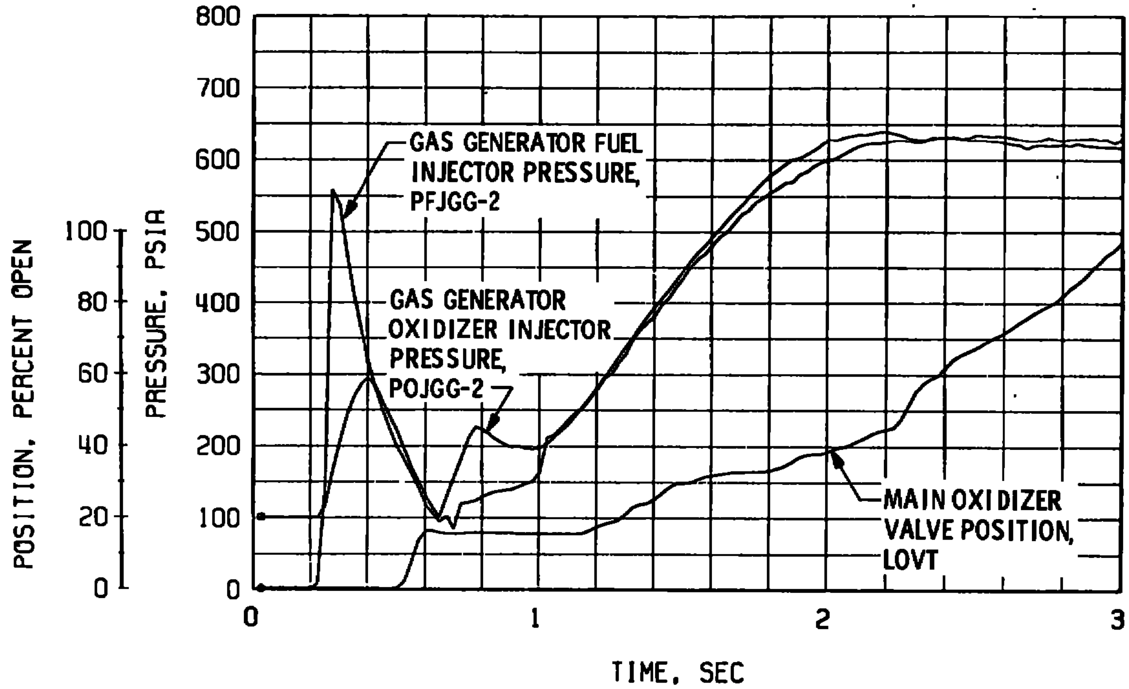


a. Thrust Chamber Fuel System, Start

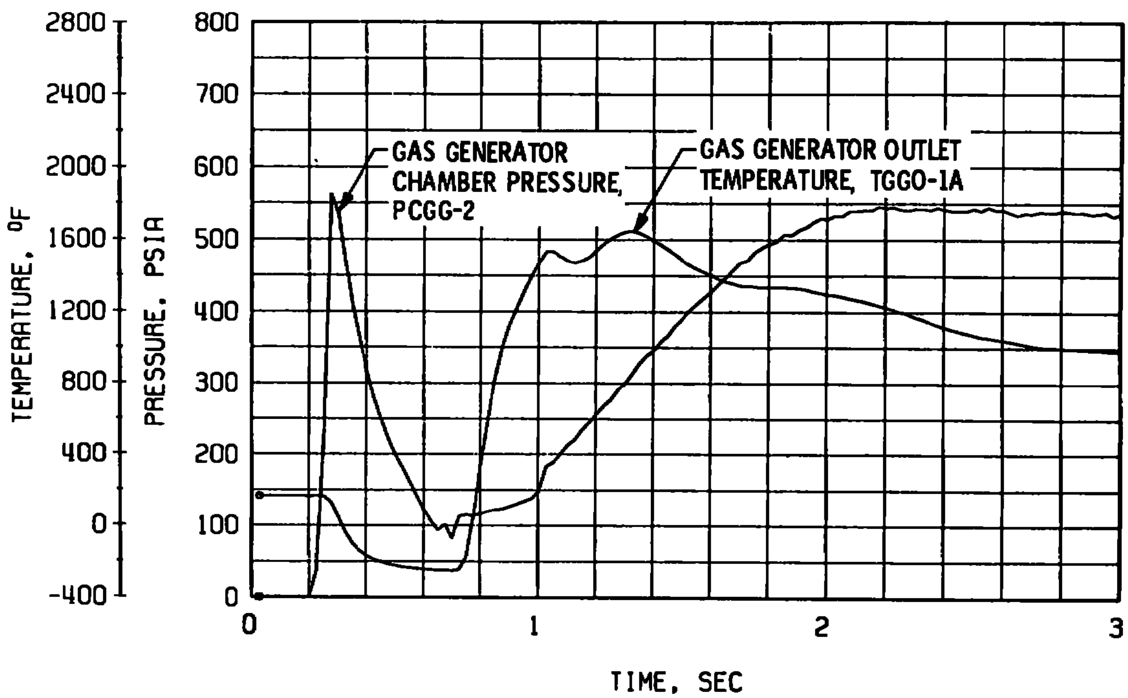


b. Thrust Chamber Oxidizer System, Start

Fig. 24 Engine Transient Operation, Firing 25B

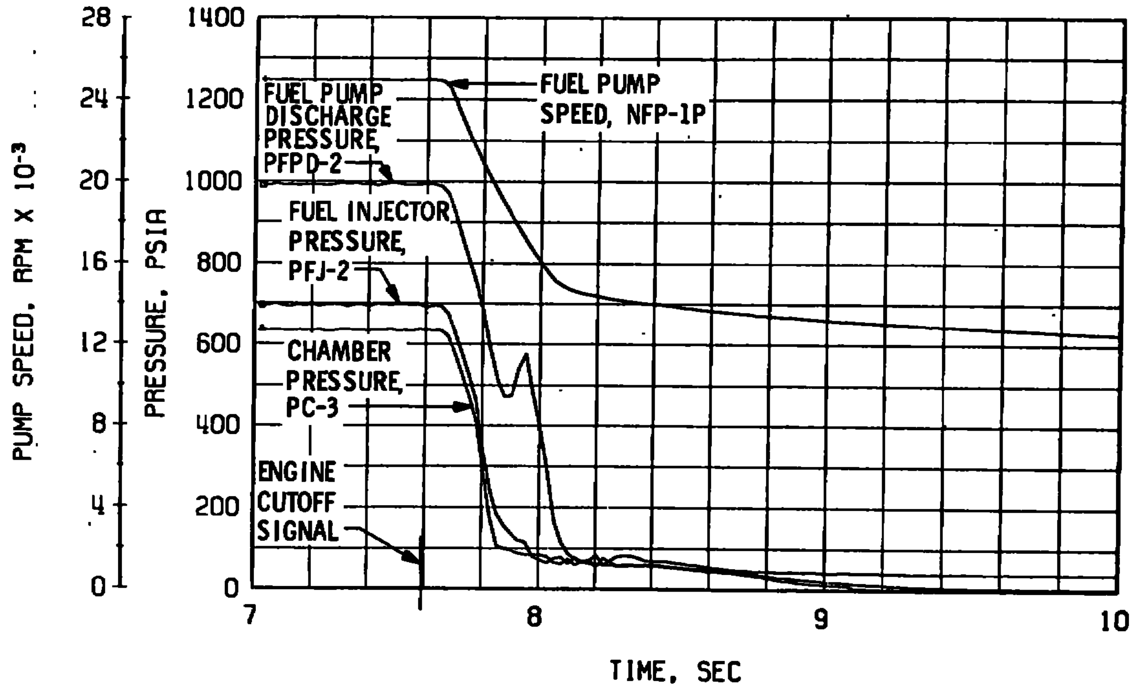


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

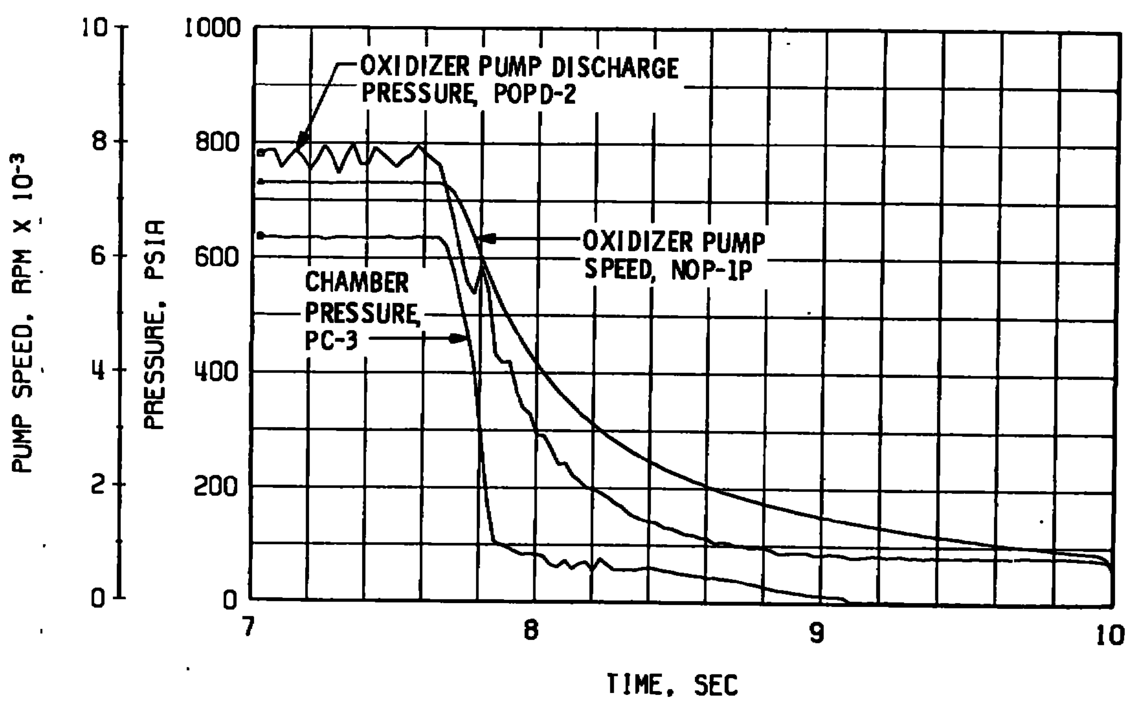


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 24 Continued

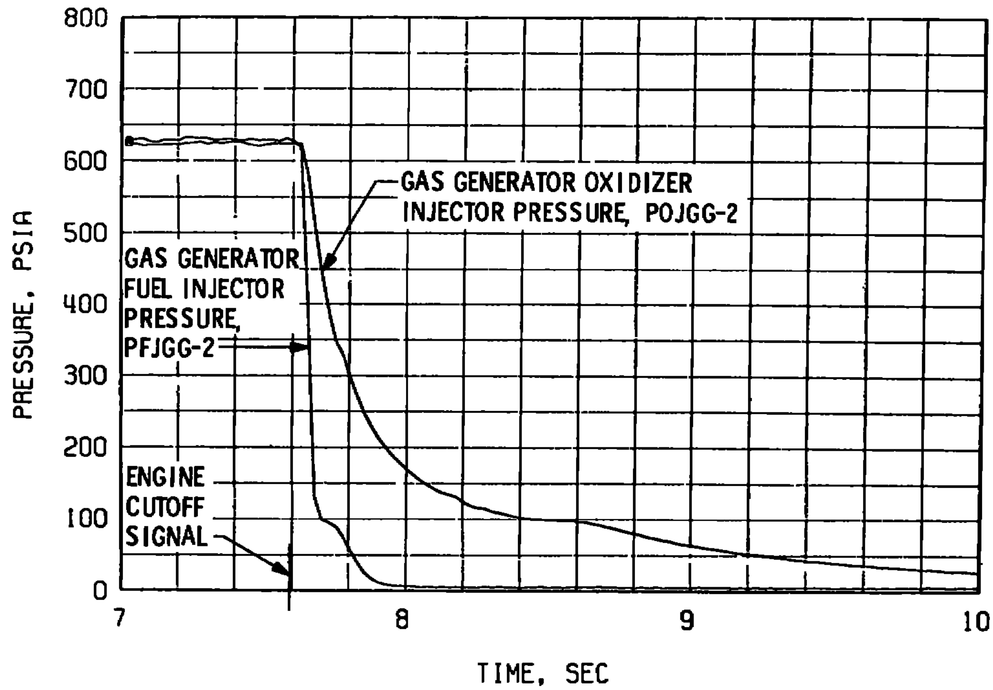


e. Thrust Chamber Fuel System, Shutdown

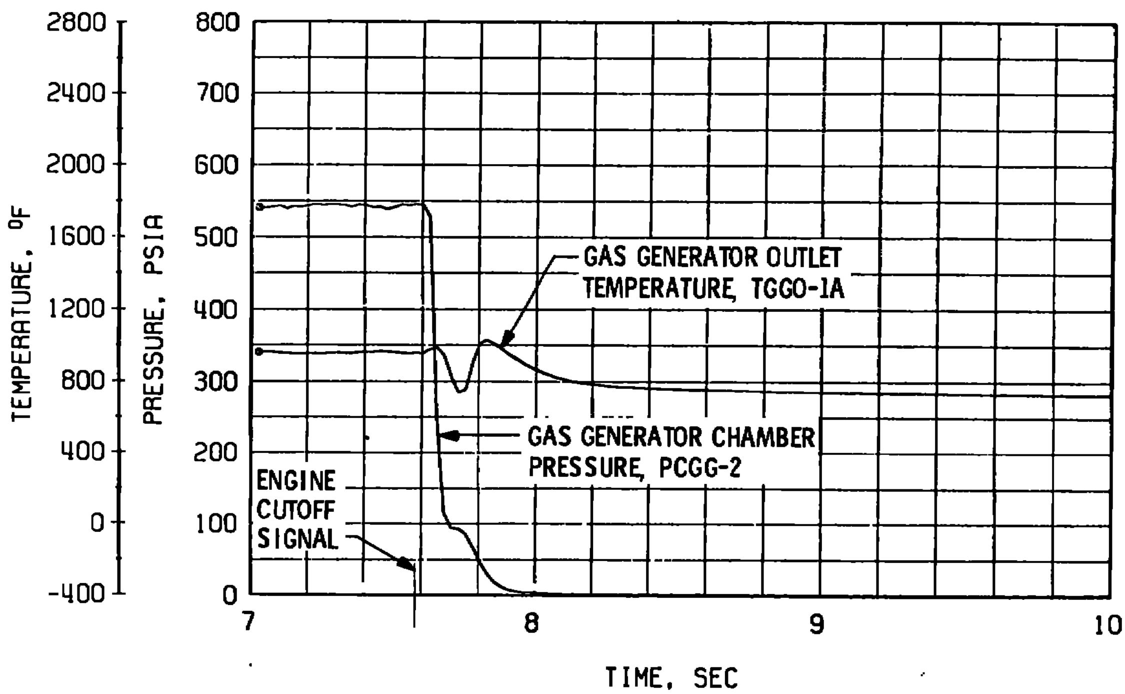


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 24 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown
Fig. 24 Concluded

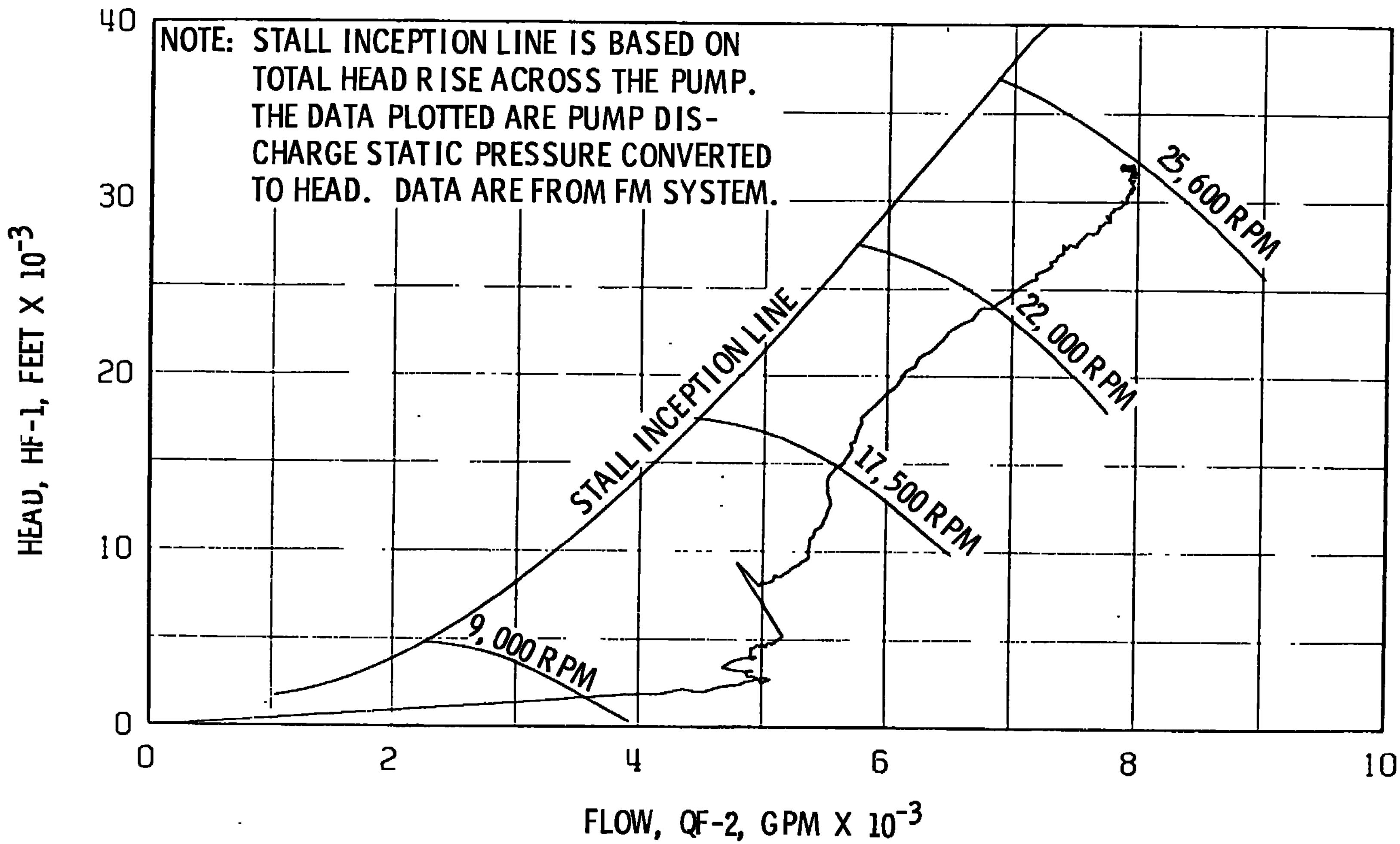
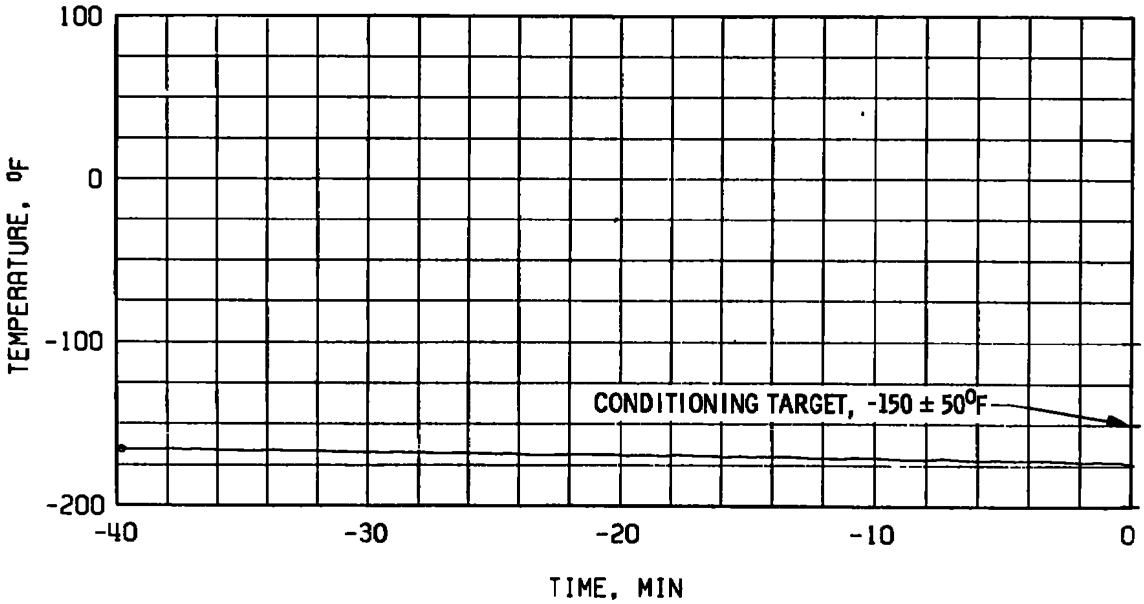
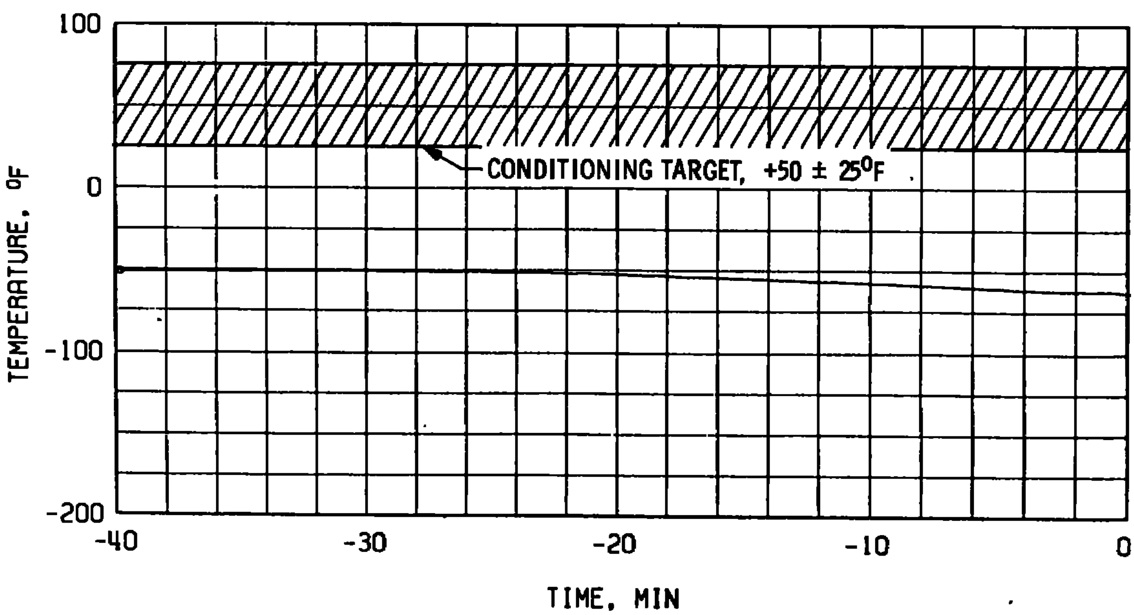


Fig. 25 Fuel Pump Start Transient Performance, Firing 25B

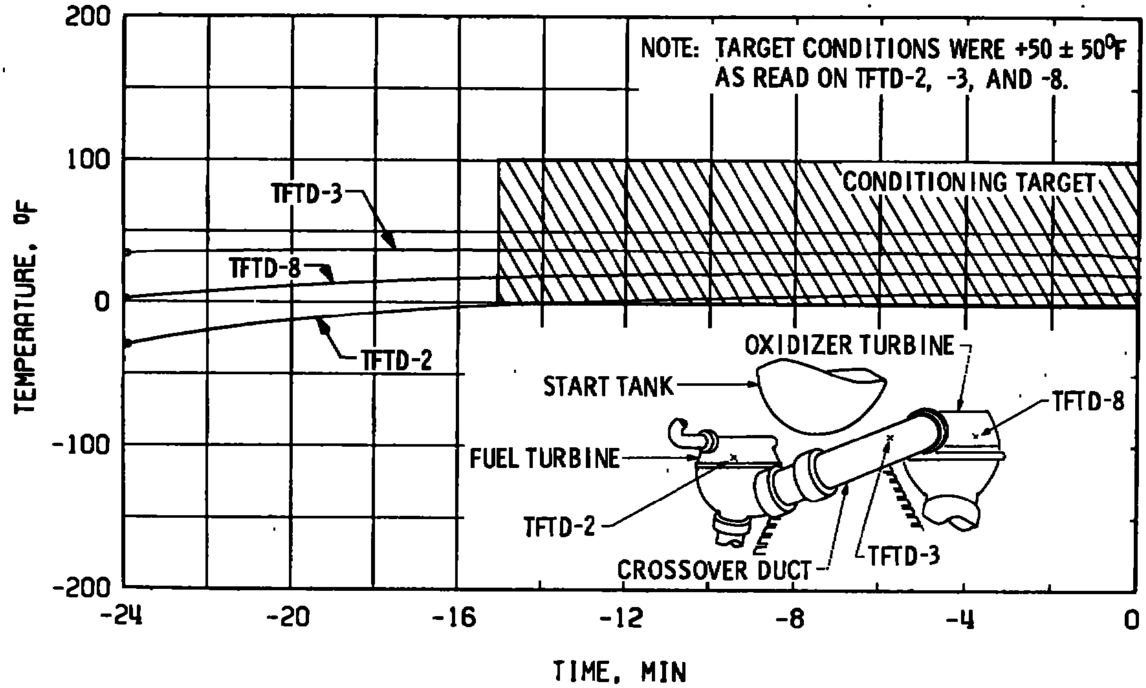


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

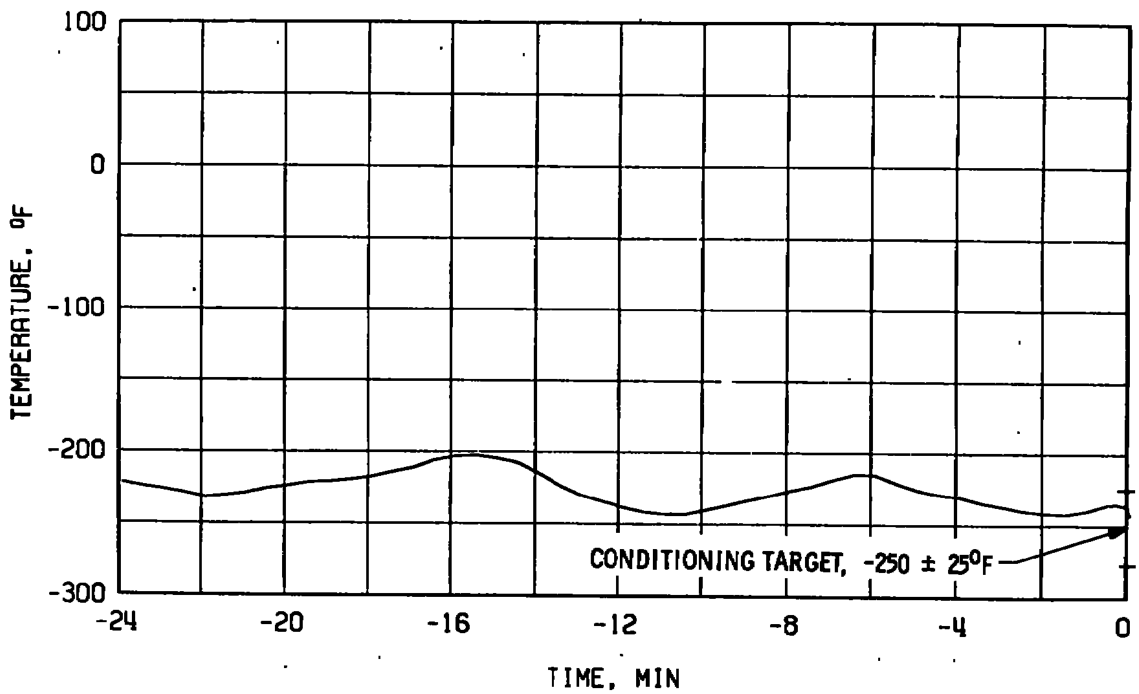


b. Start Tank Discharge Valve, TSTDVOC

Fig. 26 Thermal Conditioning History of Engine Components, Firing 25C



c. Crossover Duct, TFTD



d. Thrust Chamber Throat, TTC-1P

Fig. 26 Concluded

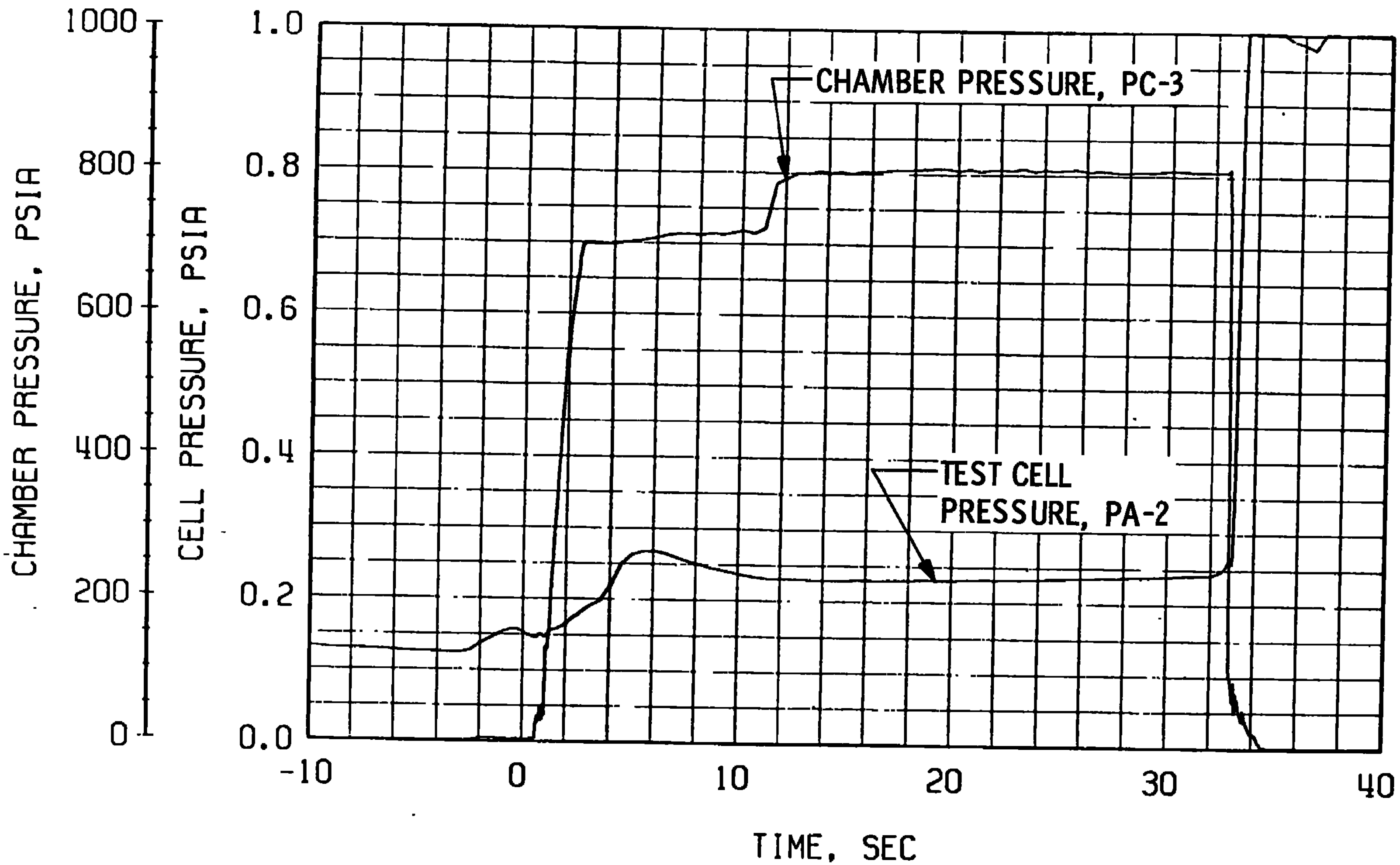
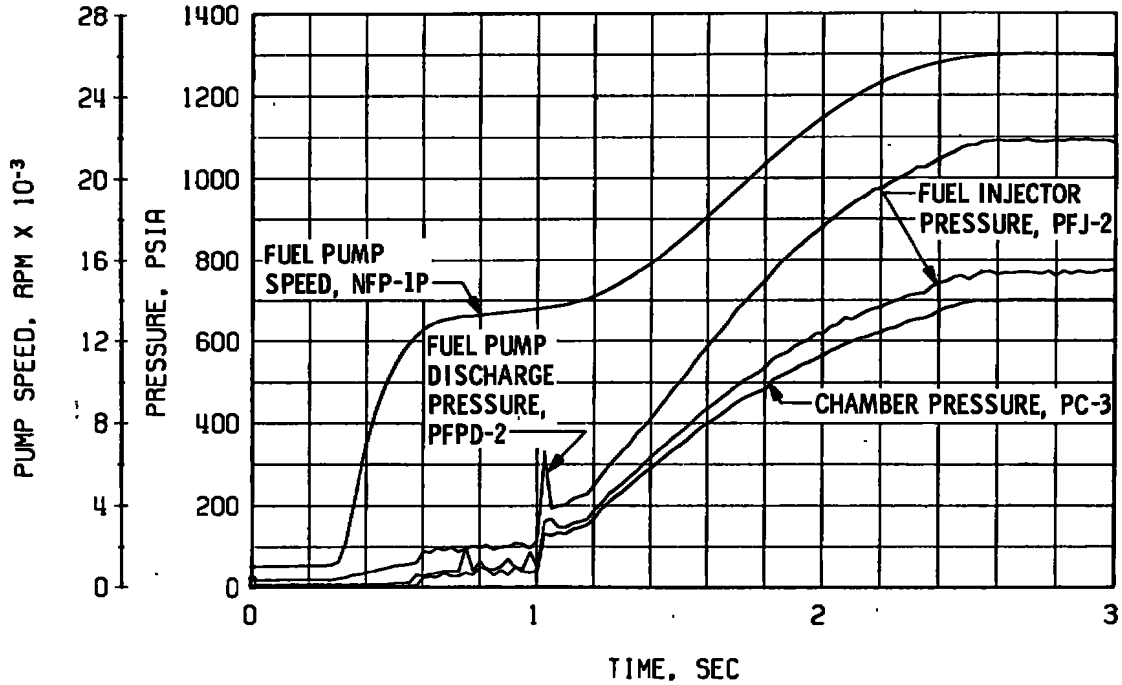
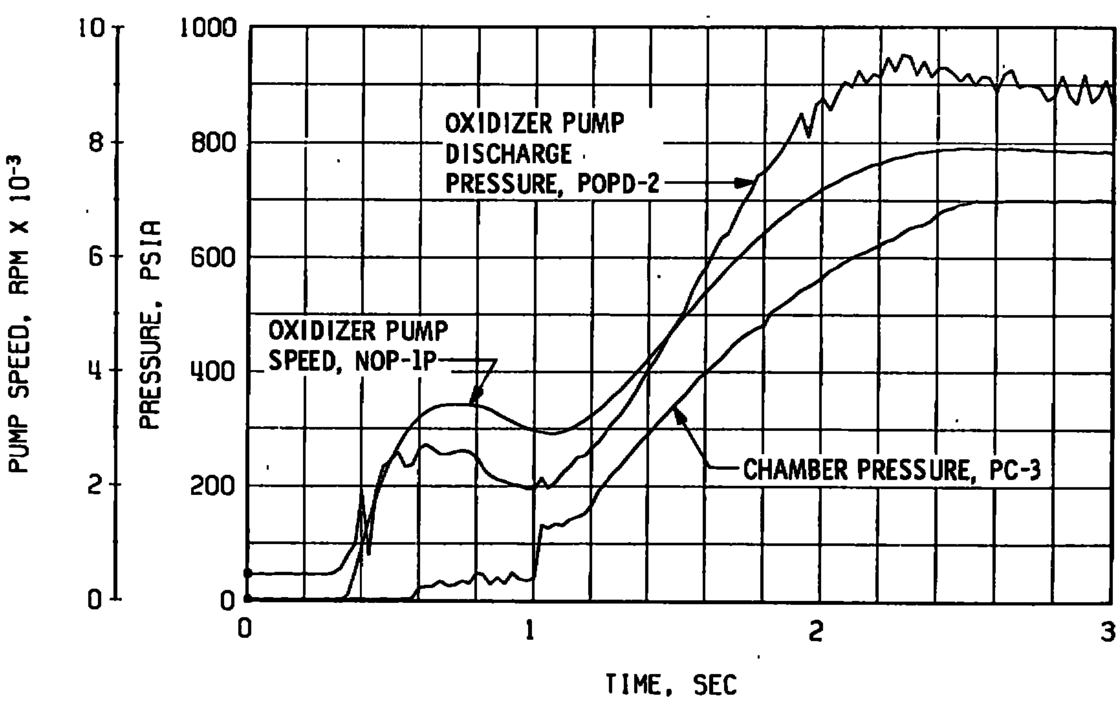


Fig. 27 Engine Ambient and Combustion Chamber Pressures, Firing 25C

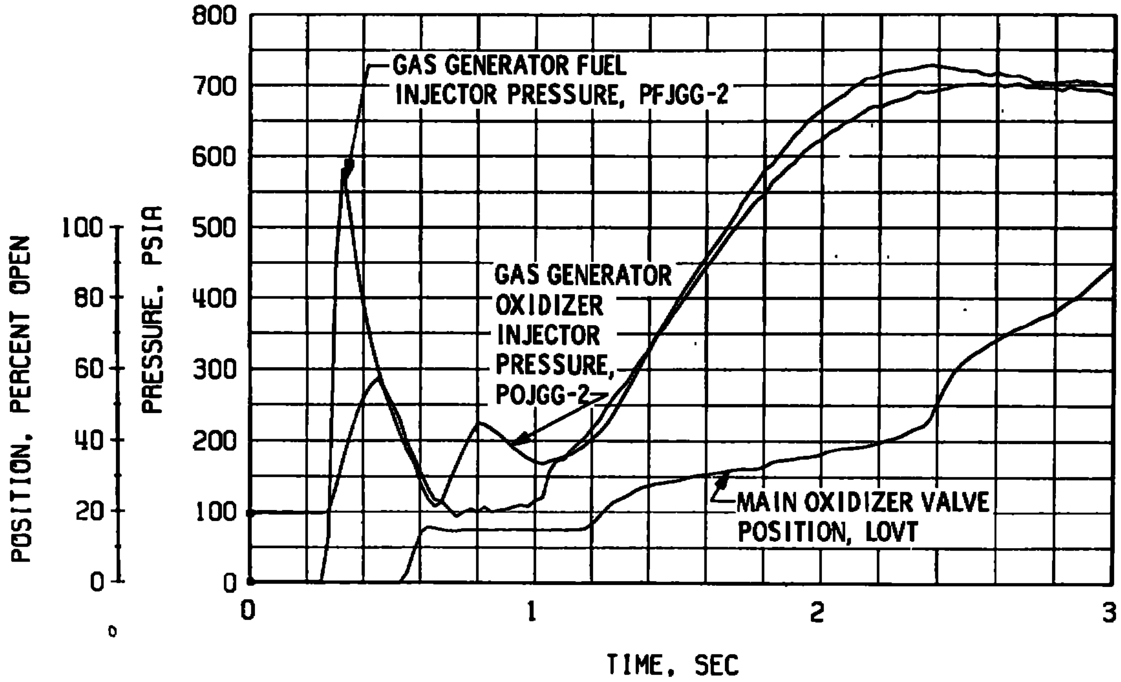


a. Thrust Chamber Fuel System, Start

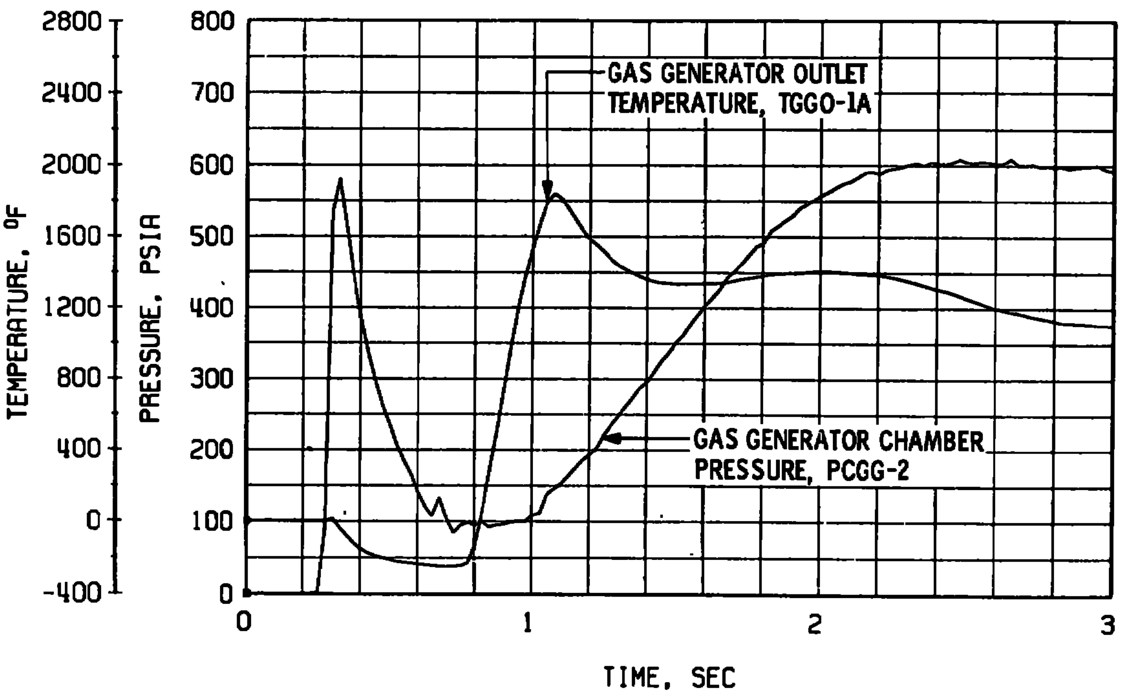


b. Thrust Chamber Oxidizer System, Start

Fig. 28 Engine Transient Operation, Firing 25C

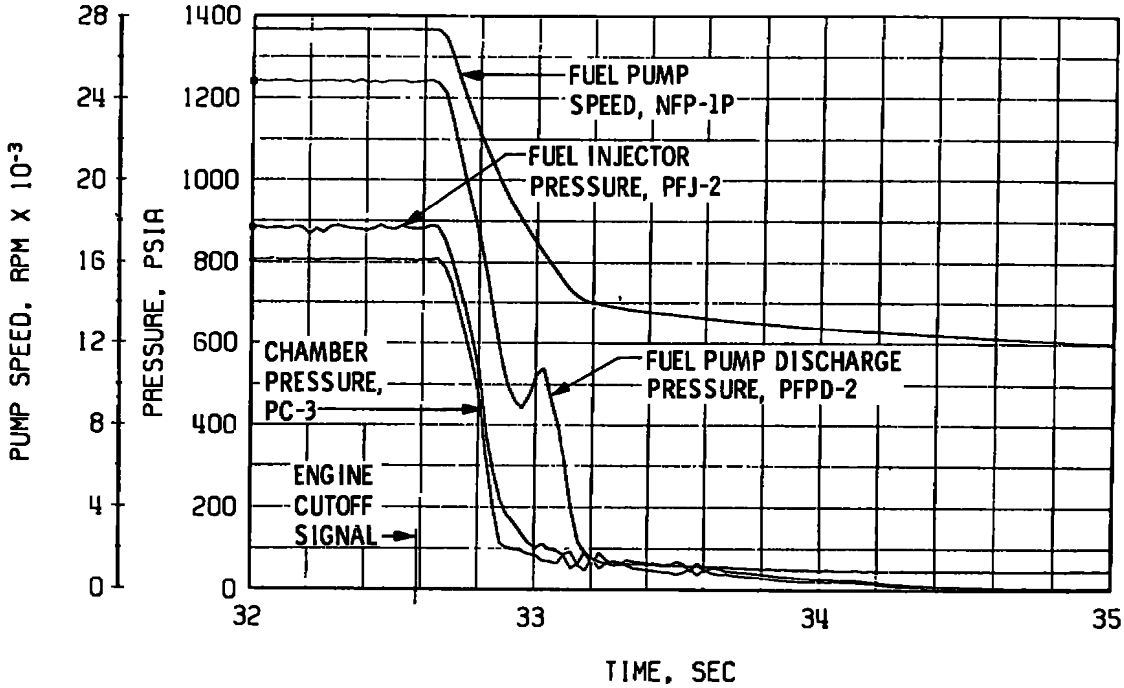


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

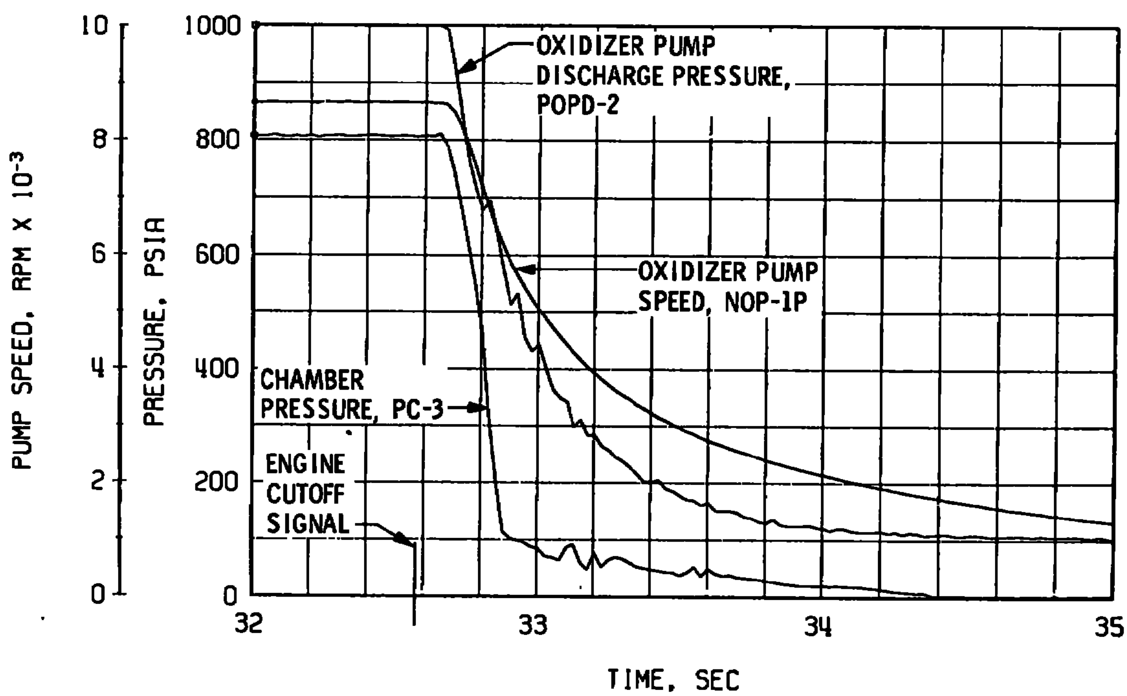


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 28 Continued

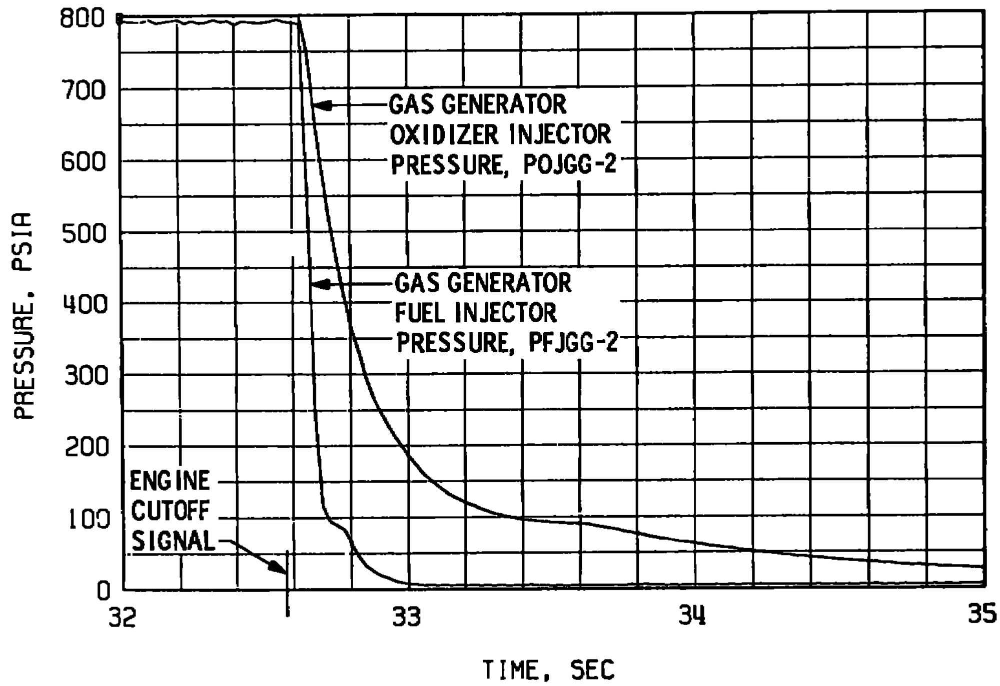


e. **Thrust Chamber Fuel System, Shutdown**

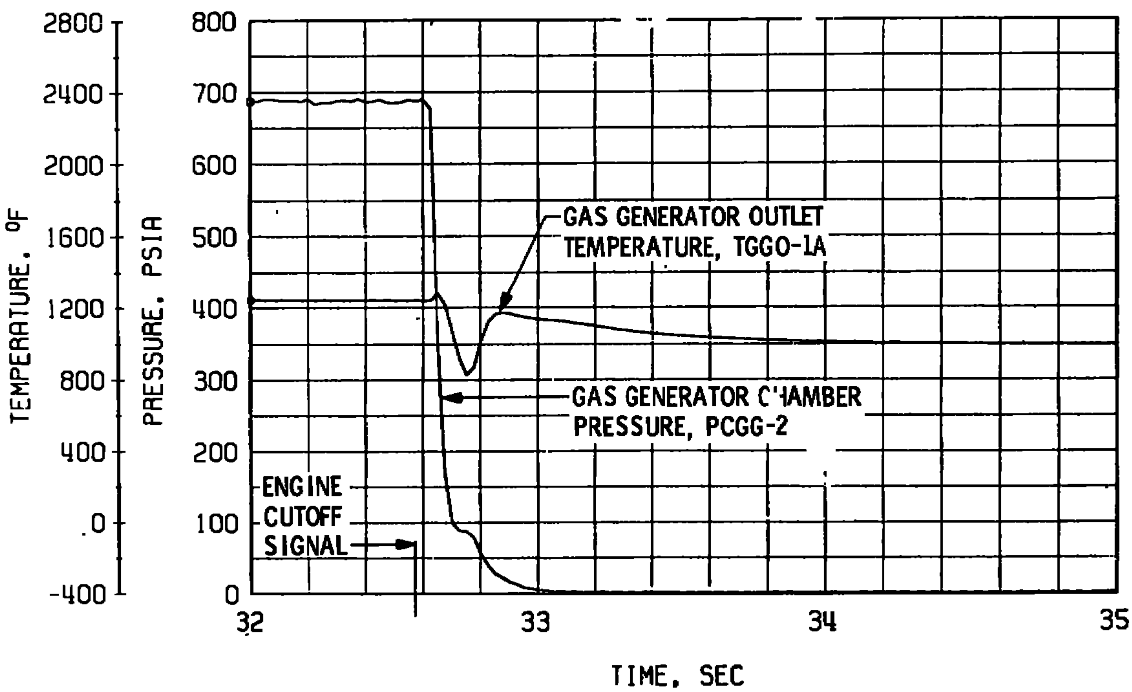


f. **Thrust Chamber Oxidizer System, Shutdown**

Fig. 28 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 28 Concluded

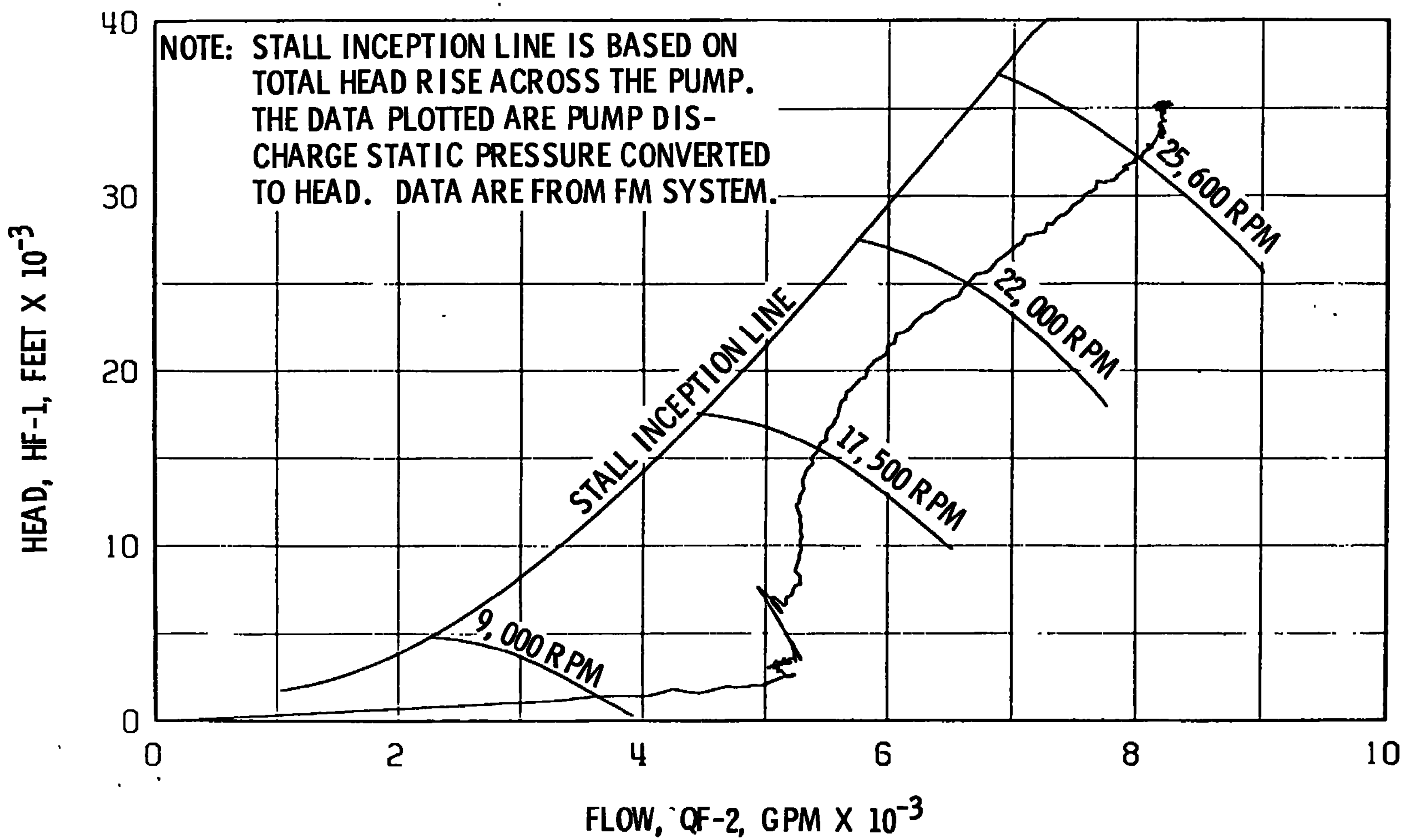


Fig. 29 Fuel Pump Start Transient Performance, Firing 25C

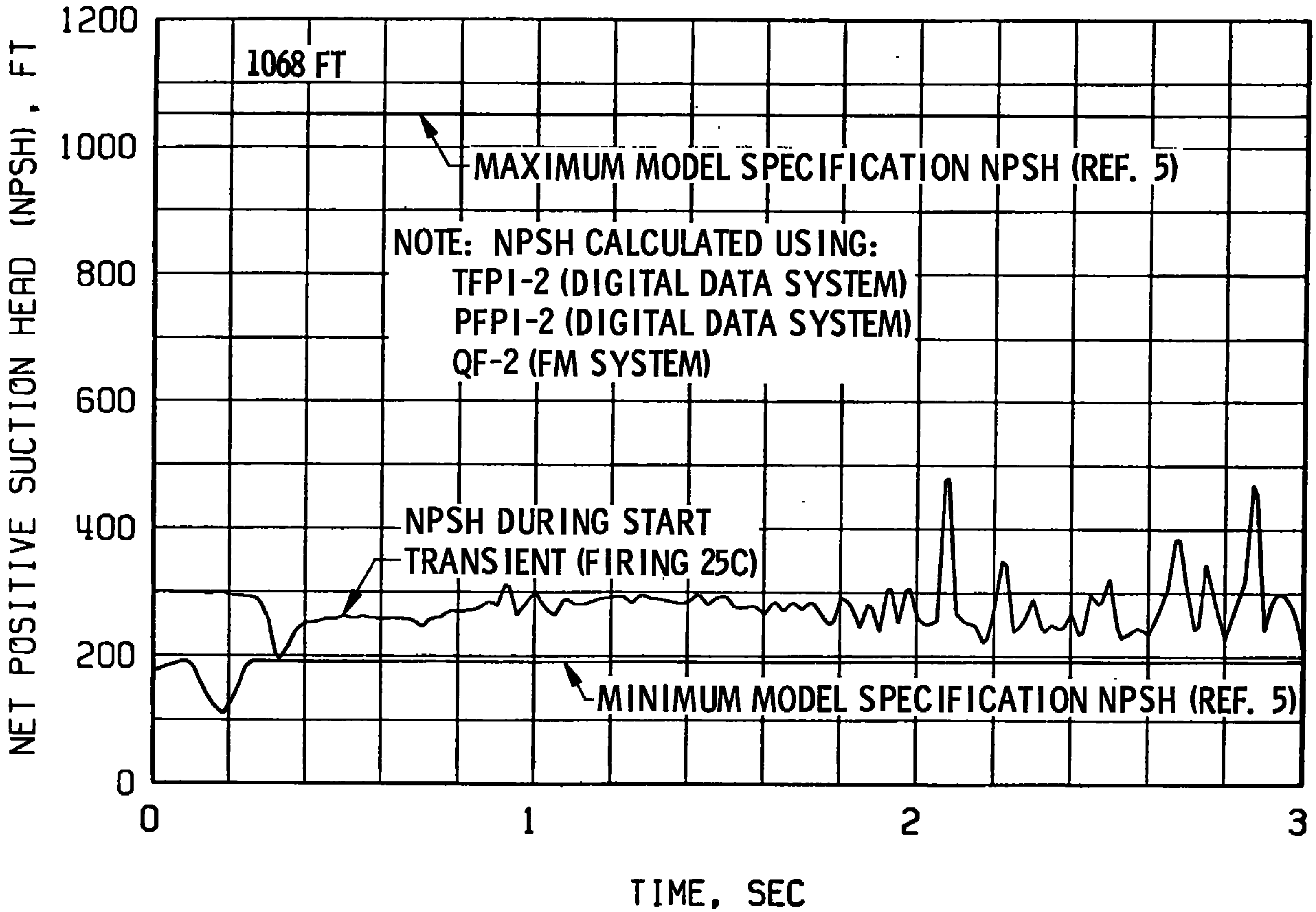


Fig. 30 Fuel Pump Net Positive Suction Head during Start Transient, Firing 25C

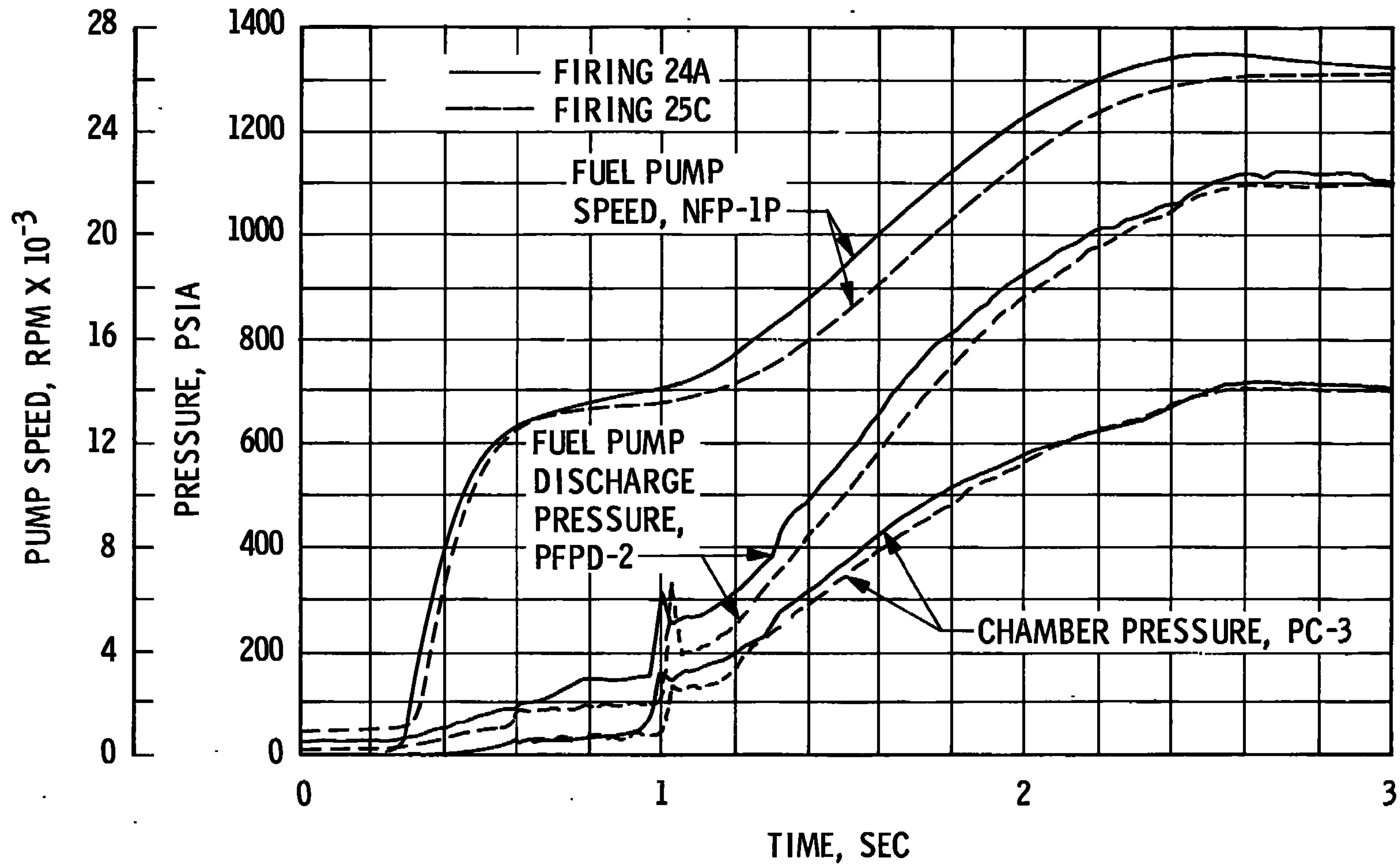


Fig. 31 Thrust Chamber Fuel System Start Transient Operations, Firings 24A and 25C

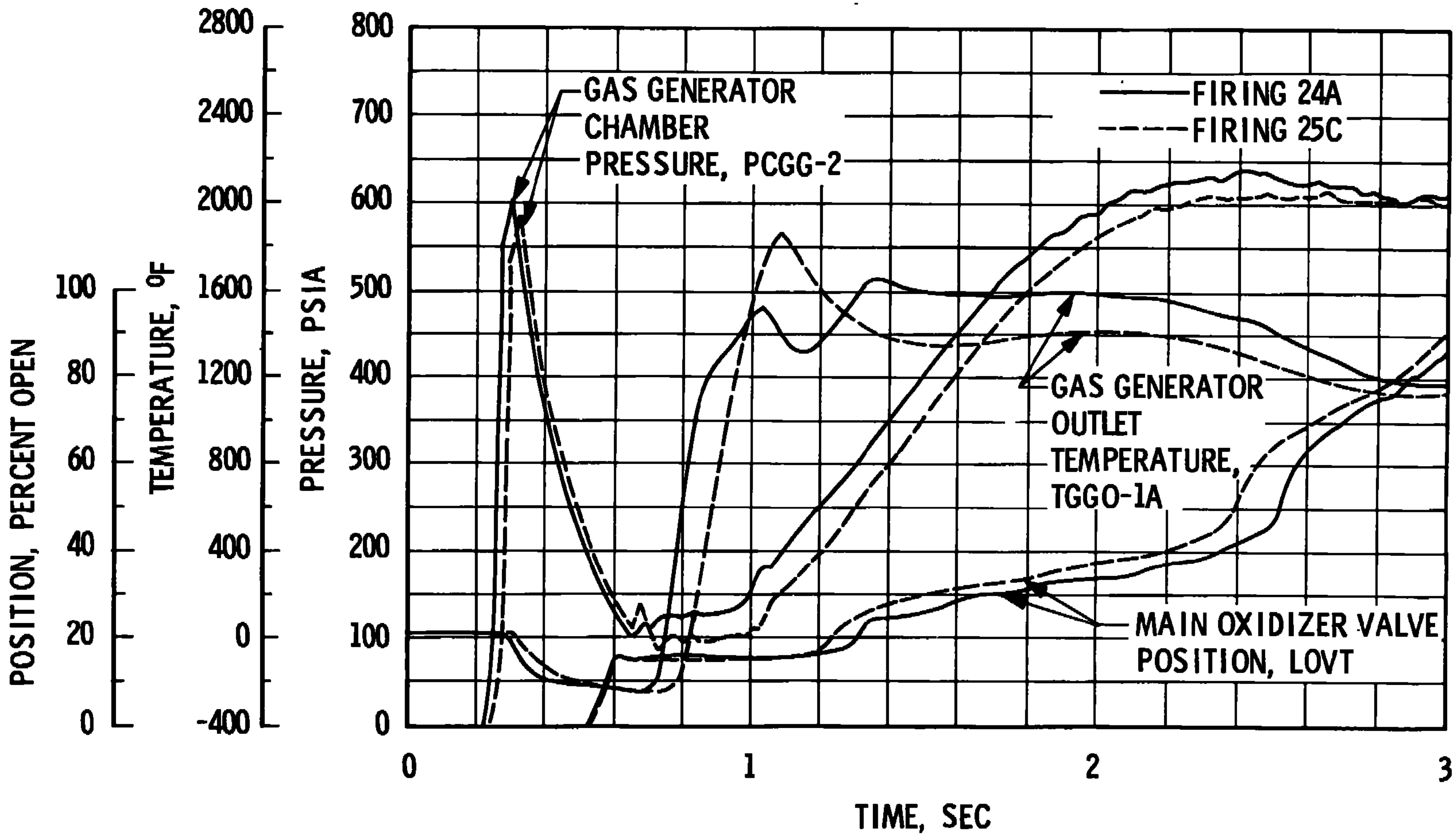


Fig. 32 Gas Generator Chamber Pressure and Temperature and Main Oxidizer Valve Start Transient Operations, Firings 24A and 25C

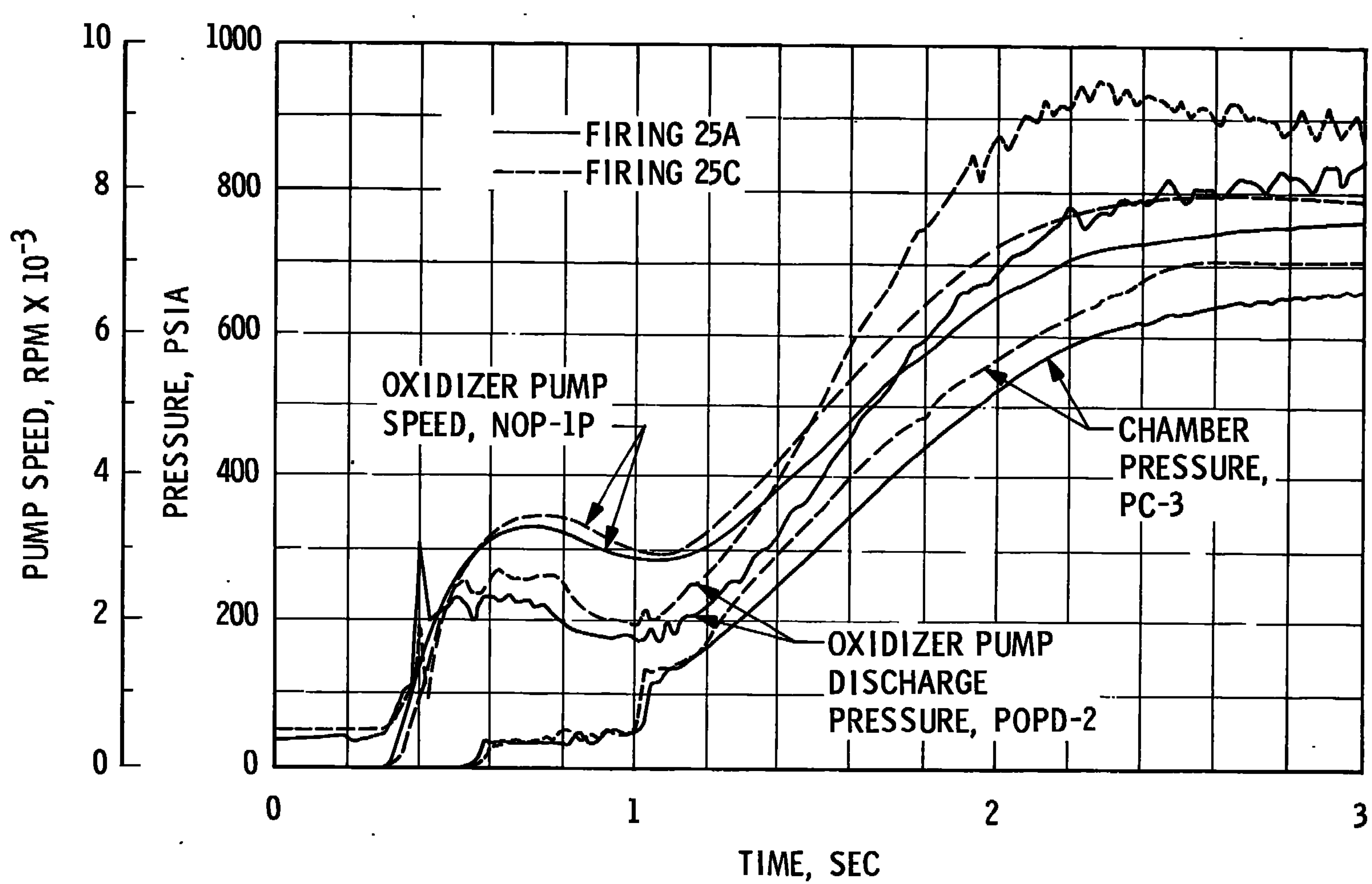


Fig. 33 Thrust Chamber Oxidizer System Start Transient Operation, Firings 25A and 25C

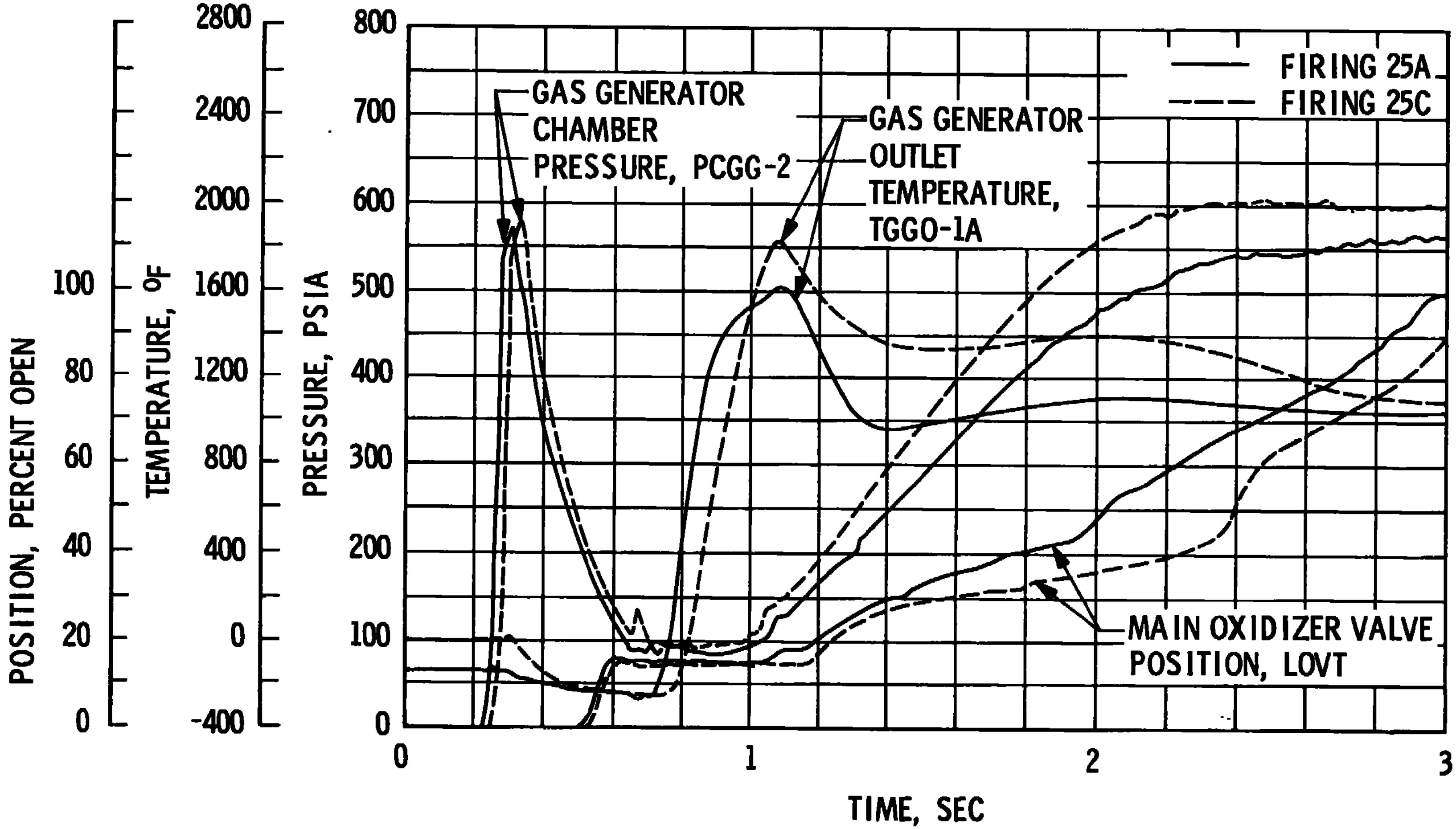
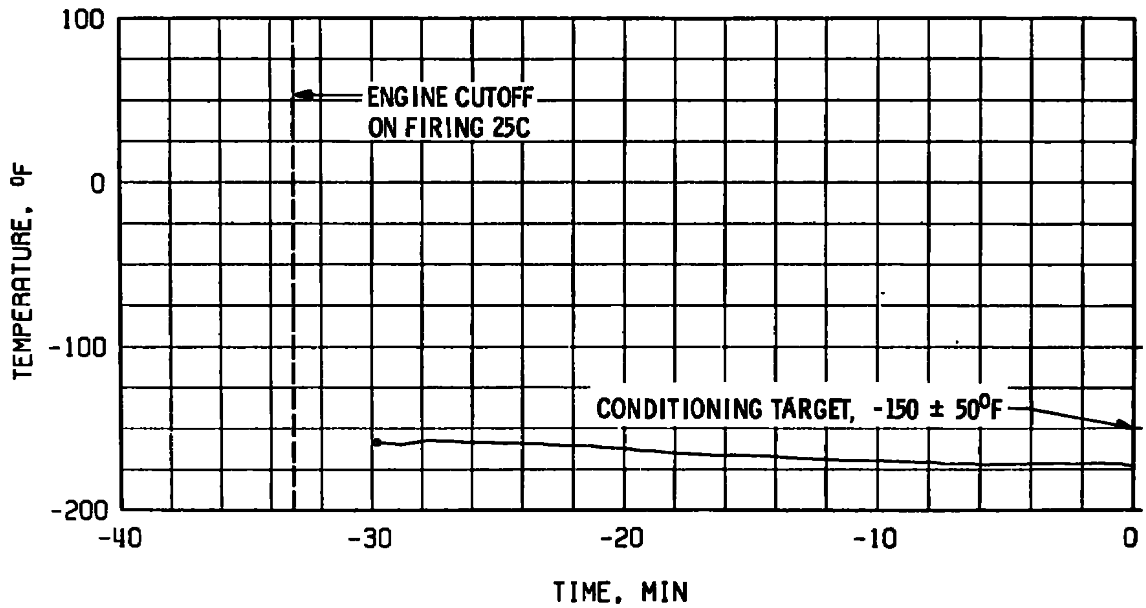
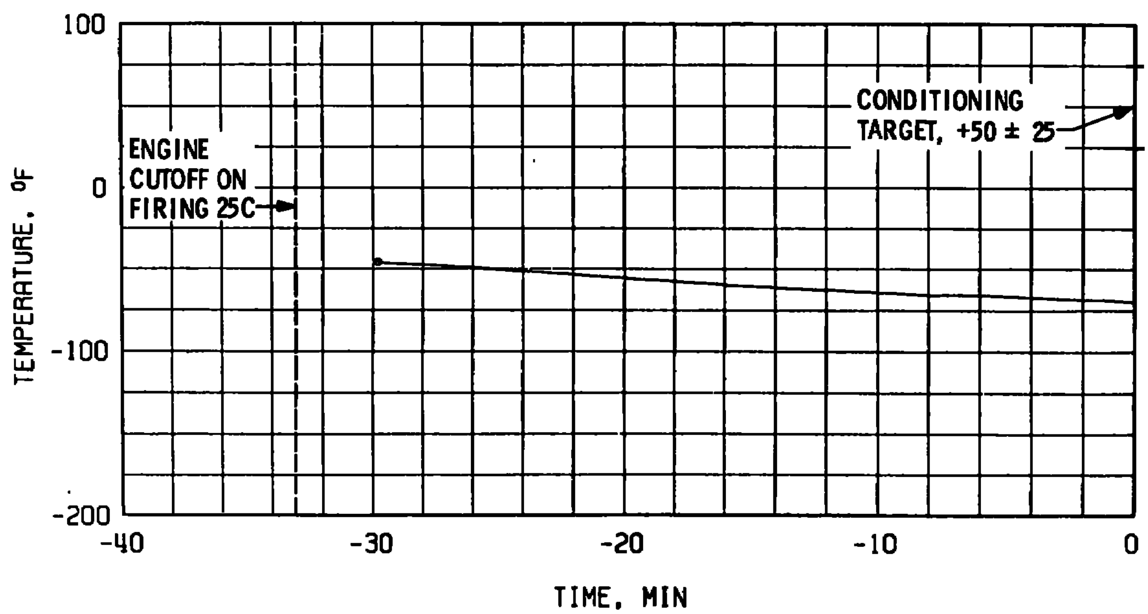


Fig. 34 Gas Generator Chamber Pressure and Temperature and Main Oxidizer Valve Start Transient Operation, Firings 25A and 25C

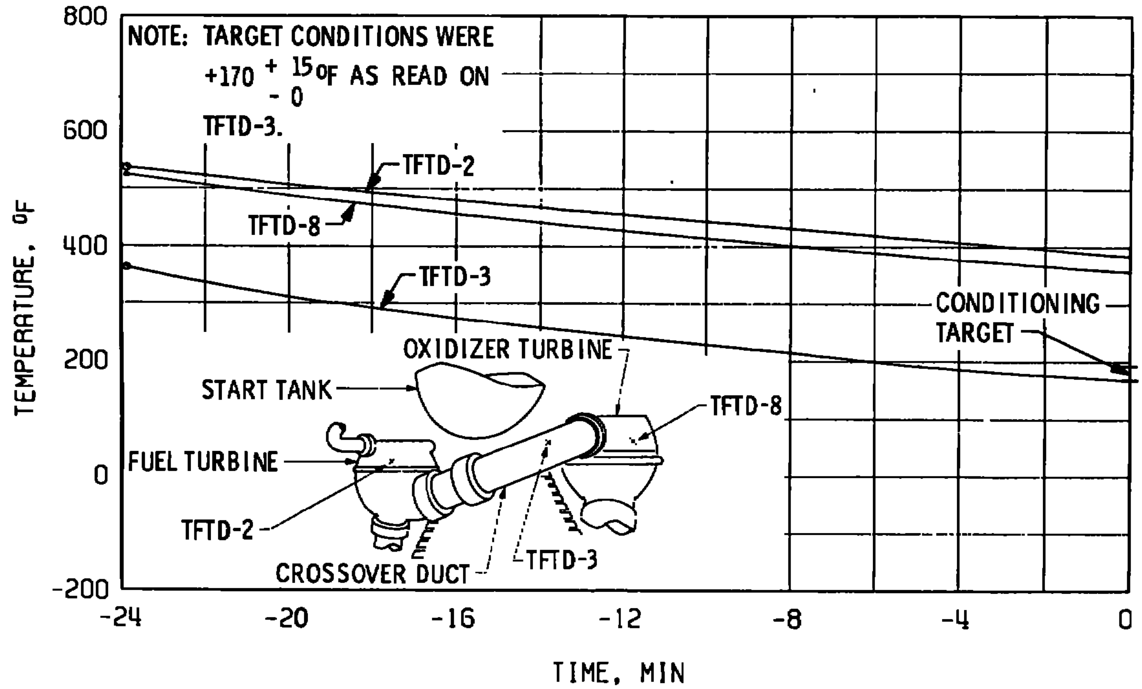


a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

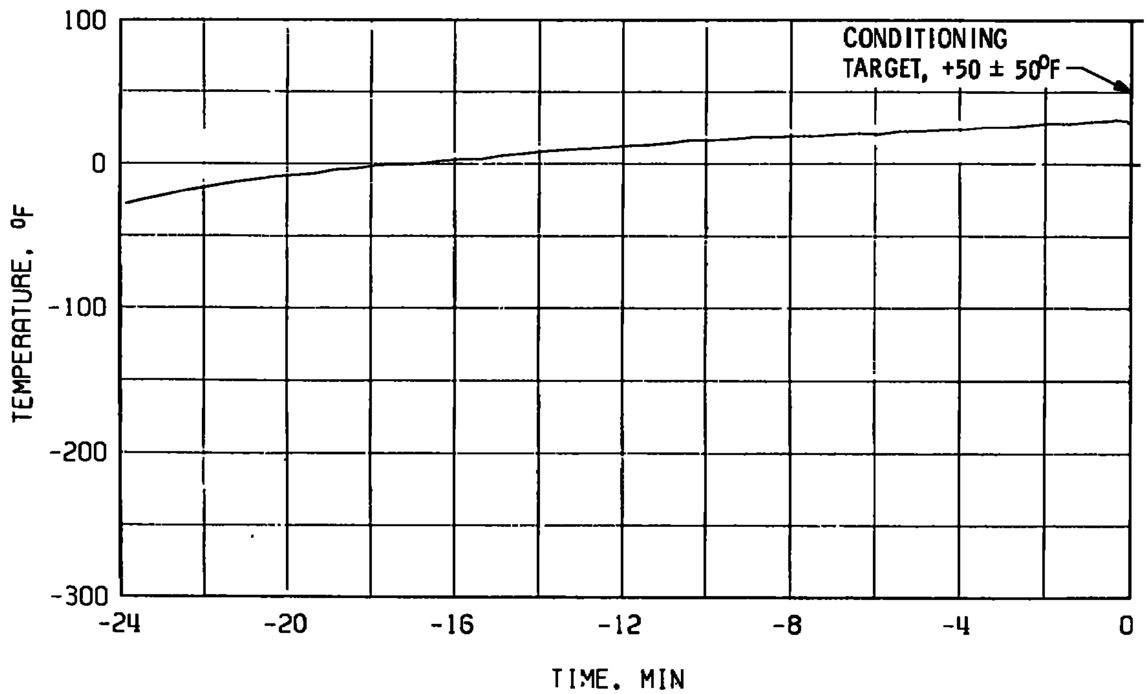


b. Start Tank Discharge Valve, TSTDVOC

Fig. 35 Thermal Conditioning History of Engine Components, Firing 25D

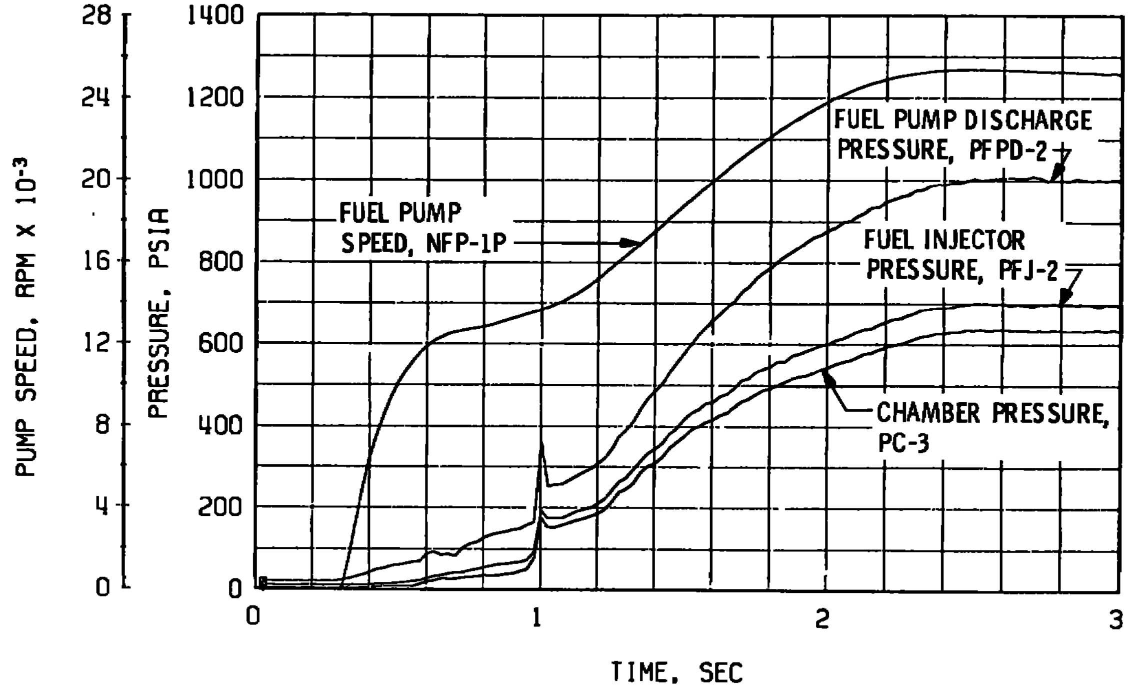


c. Crossover Duct, TFTD

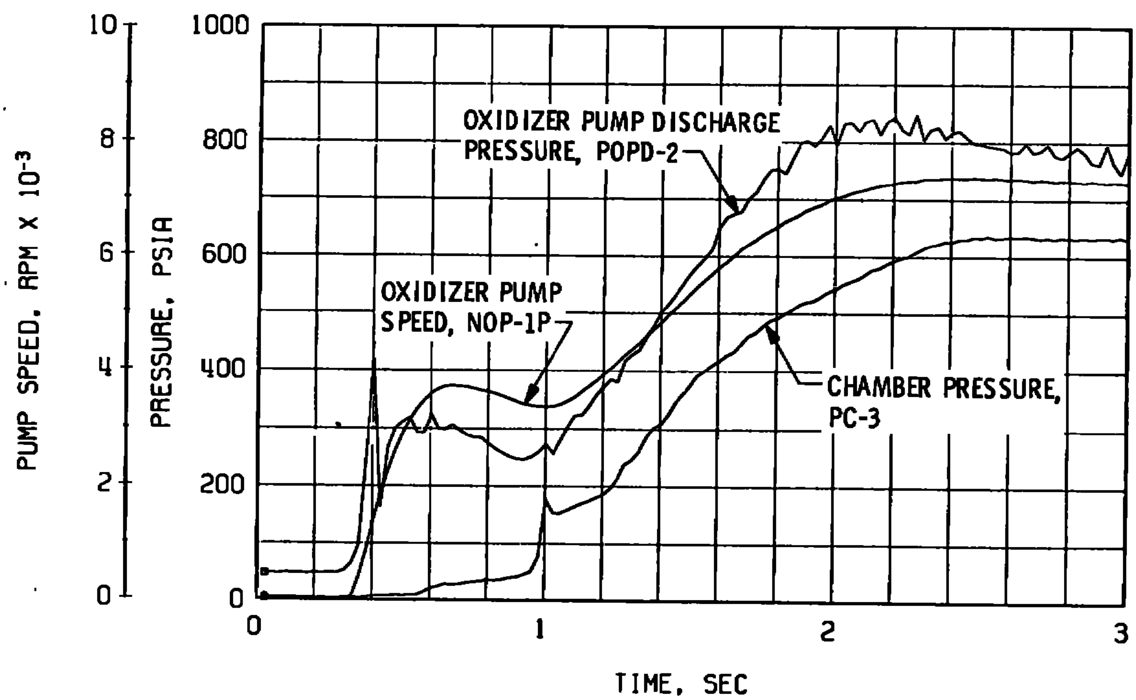


d. Thrust Chamber Throat, TTC-1P

Fig. 35 Concluded

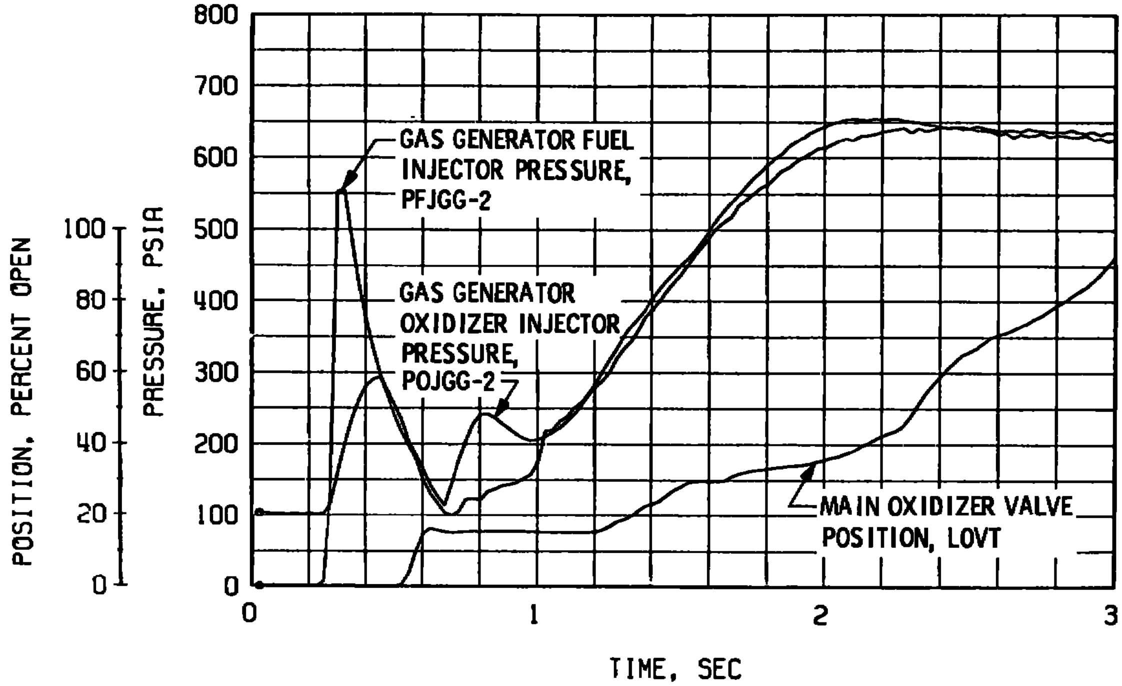


a. Thrust Chamber Fuel System, Start

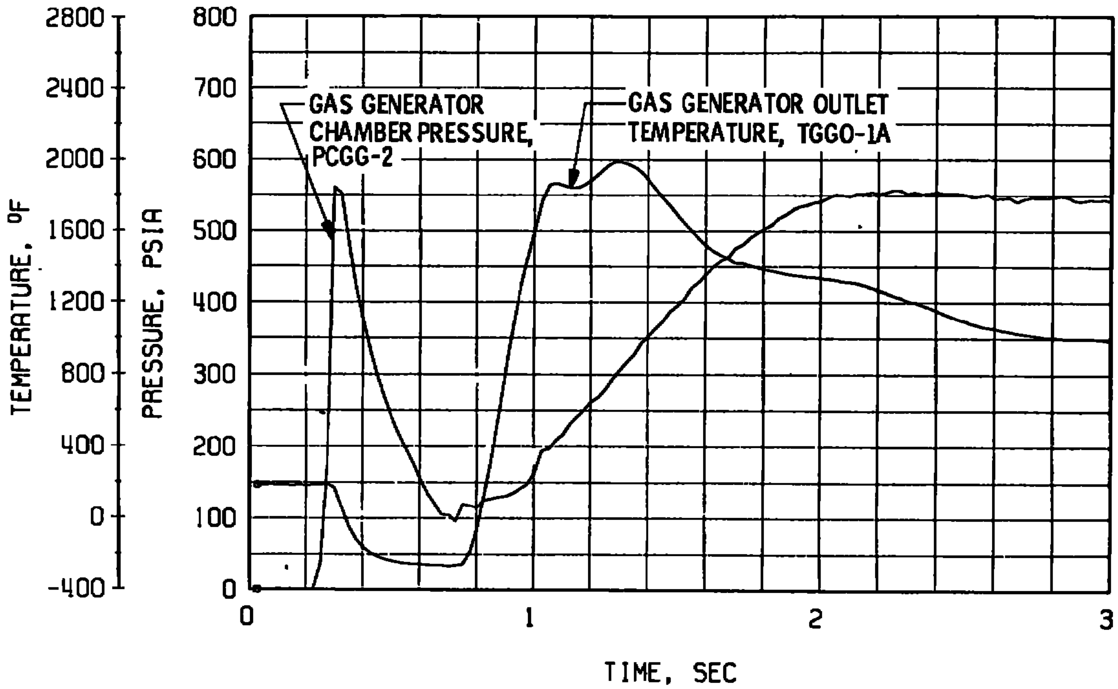


b. Thrust Chamber Oxidizer System, Start

Fig. 36 Engine Transient Operation, Firing 25D

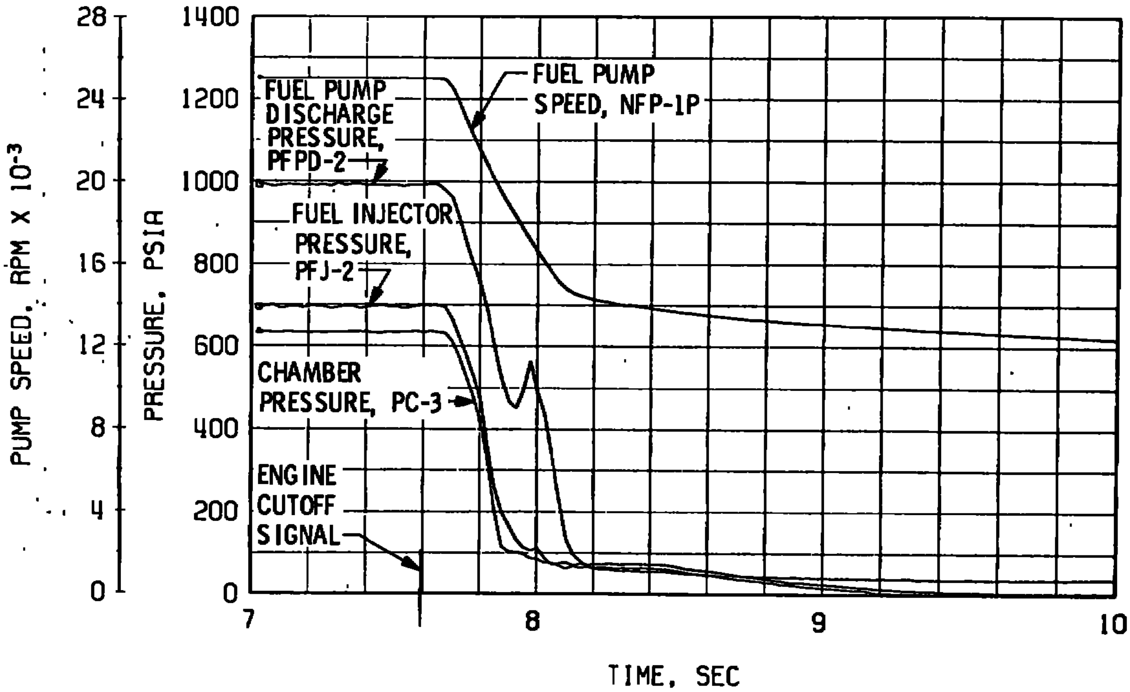


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

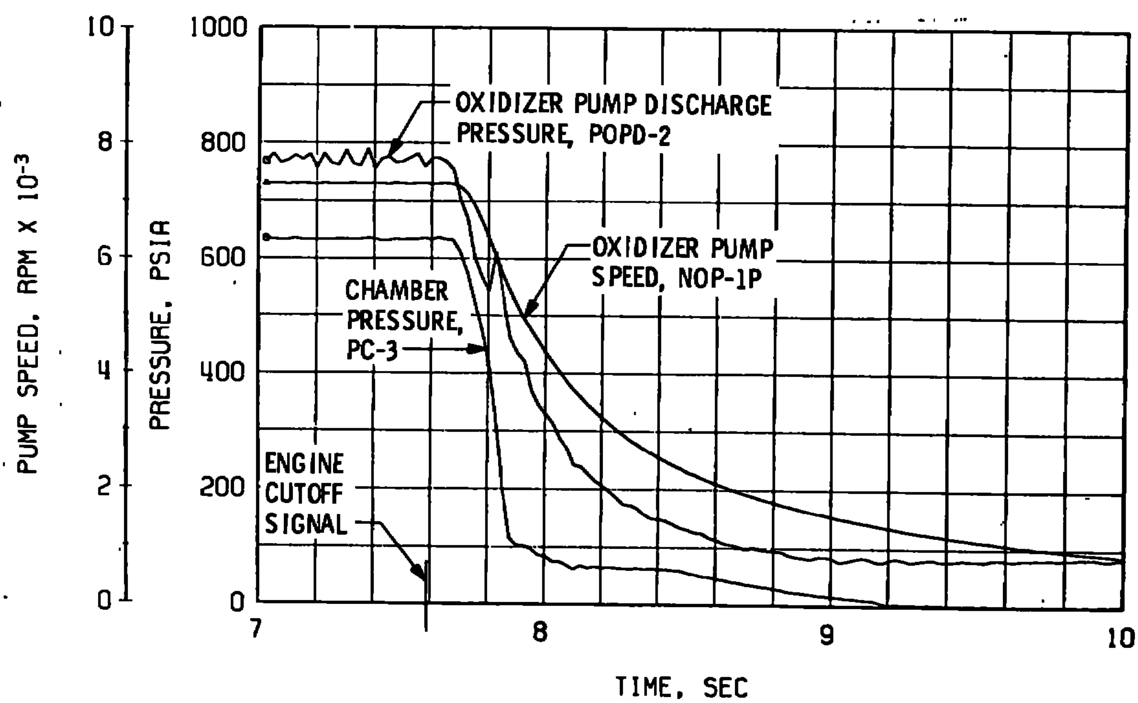


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 36 Continued

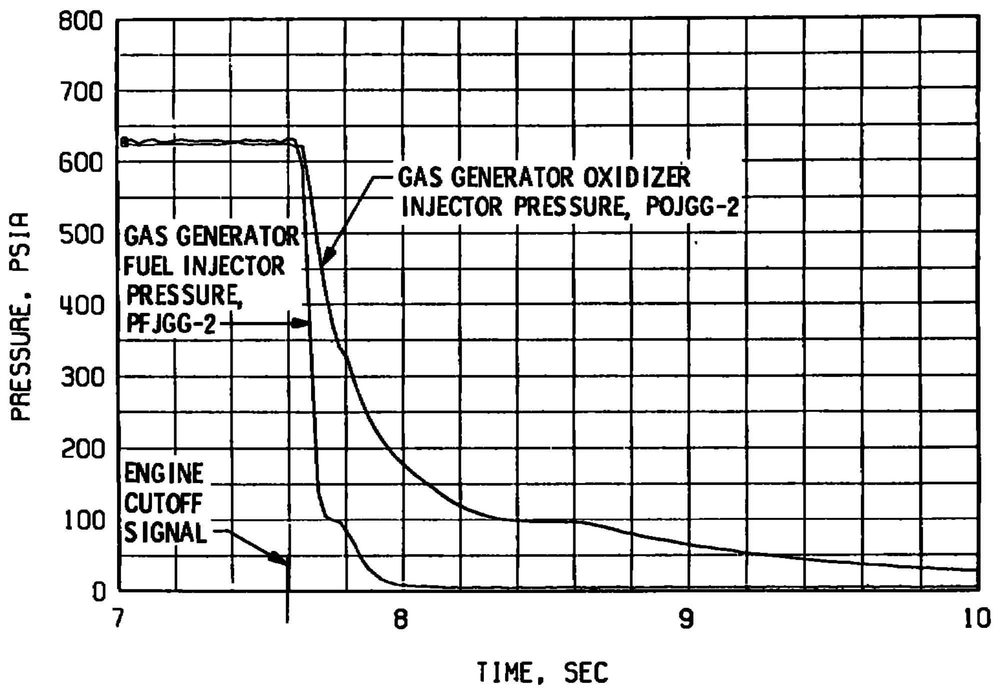


e. Thrust Chamber Fuel System, Shutdown

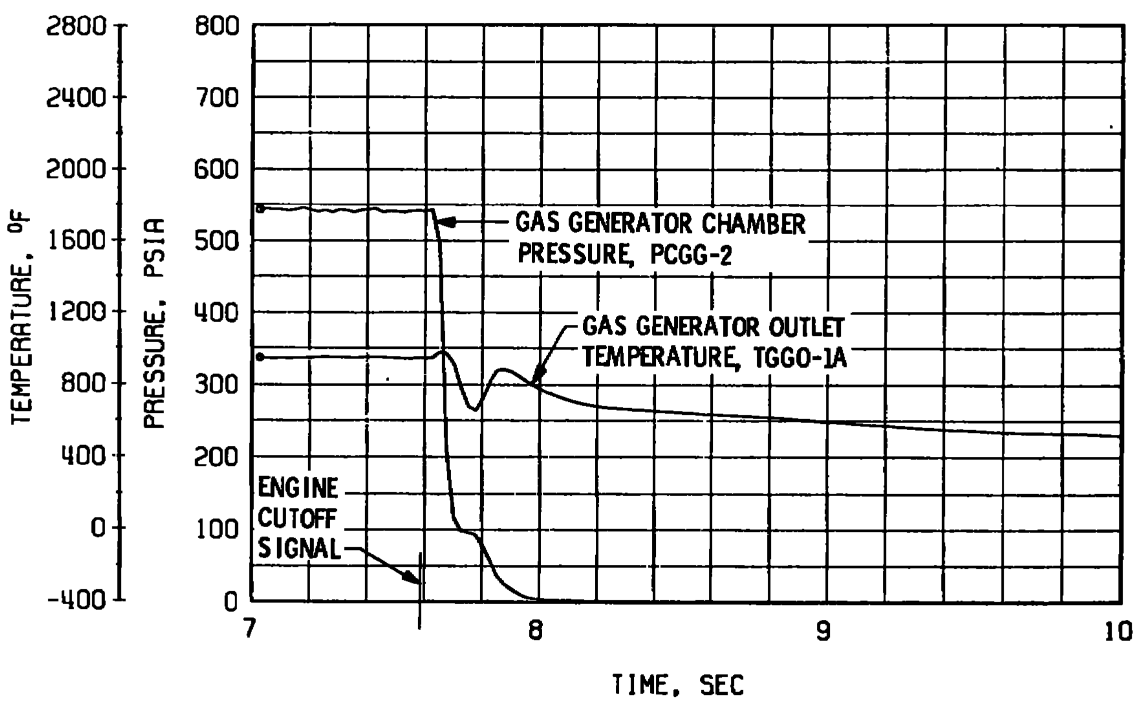


f. Thrust Chamber Oxidizer System, Shutdown

Fig 36 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 36 Concluded

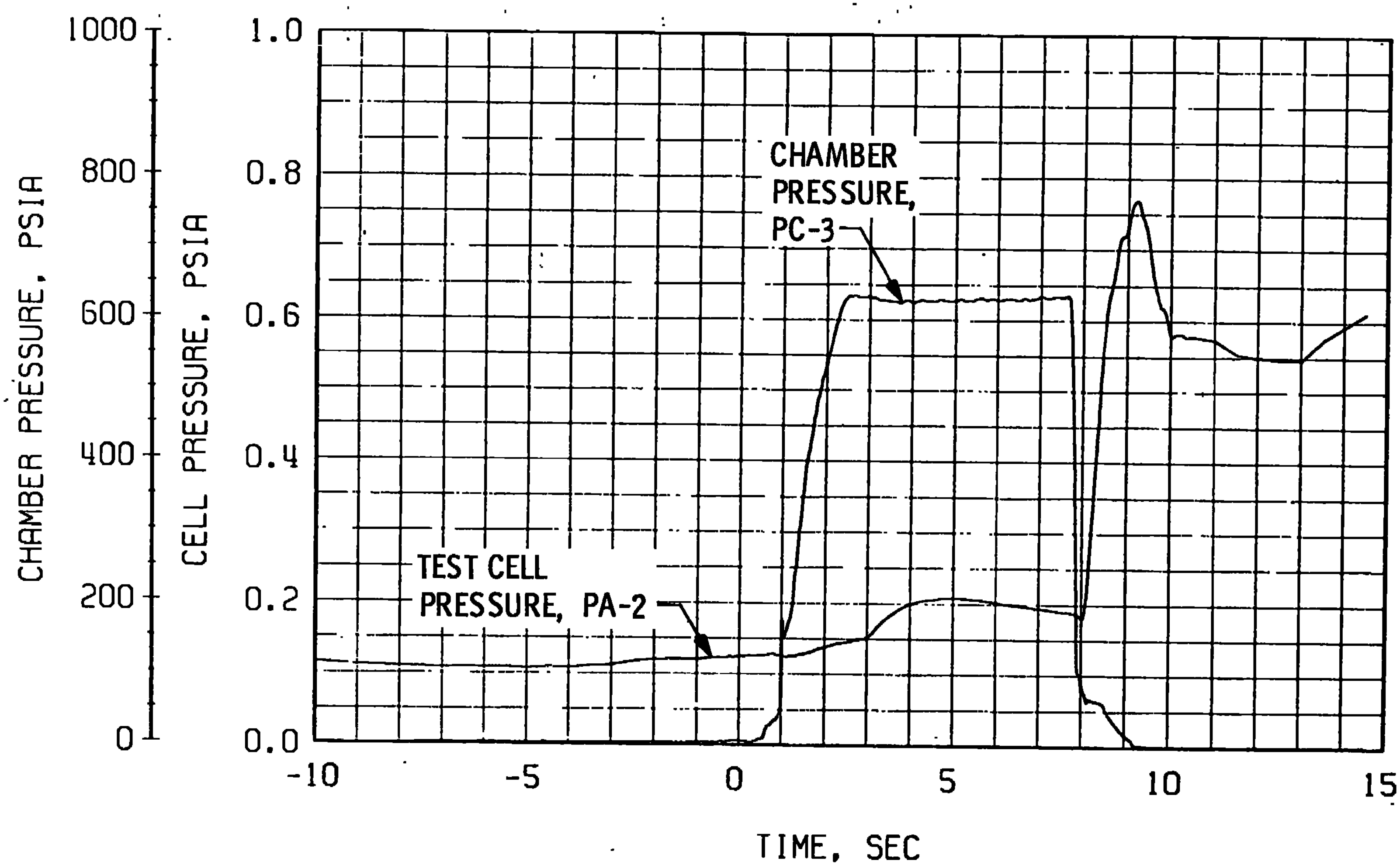


Fig. 37 Engine Ambient and Combustion Chamber Pressures, Firing 25D

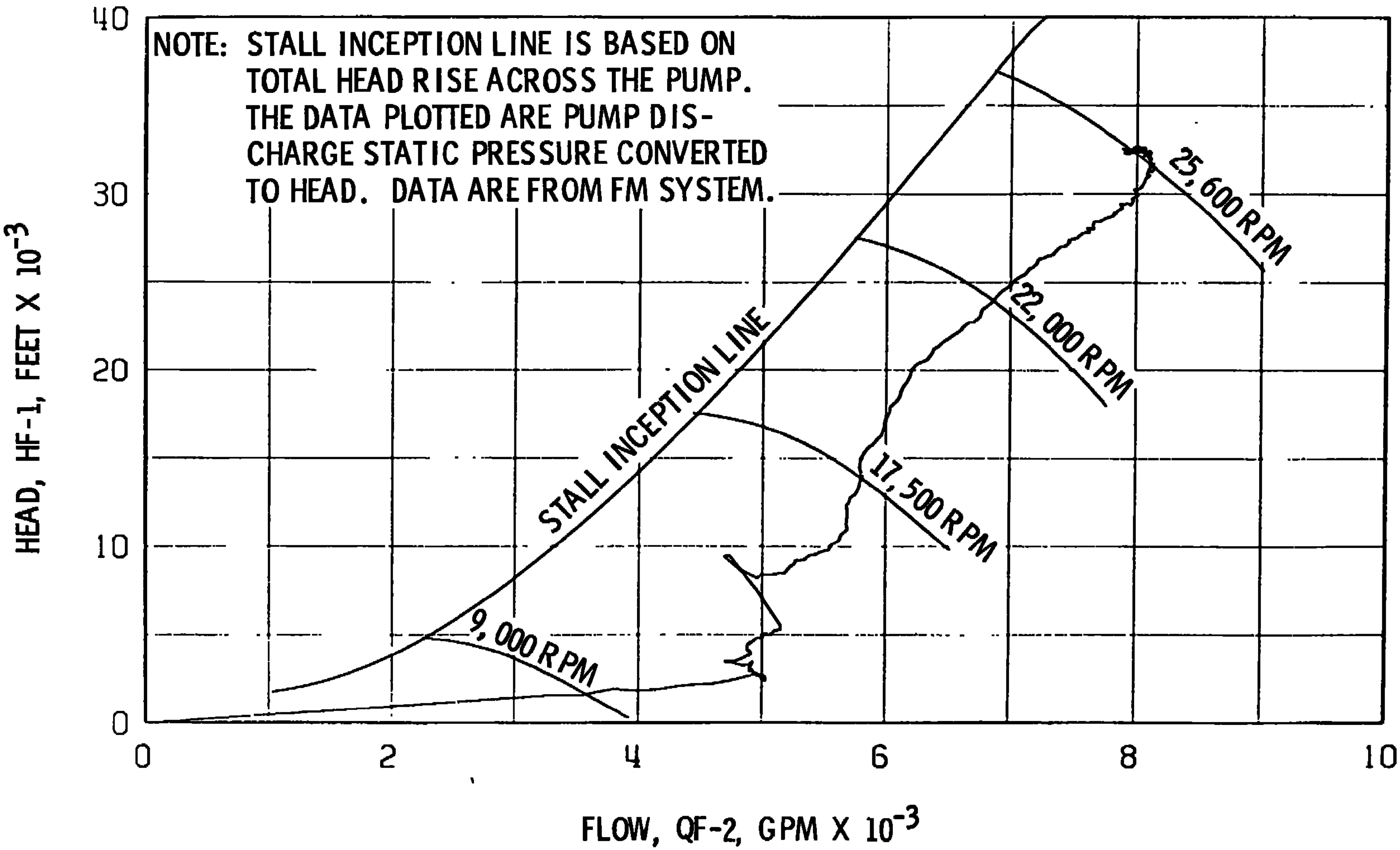


Fig. 38 Fuel Pump Start Transient Performance, Firing 25D

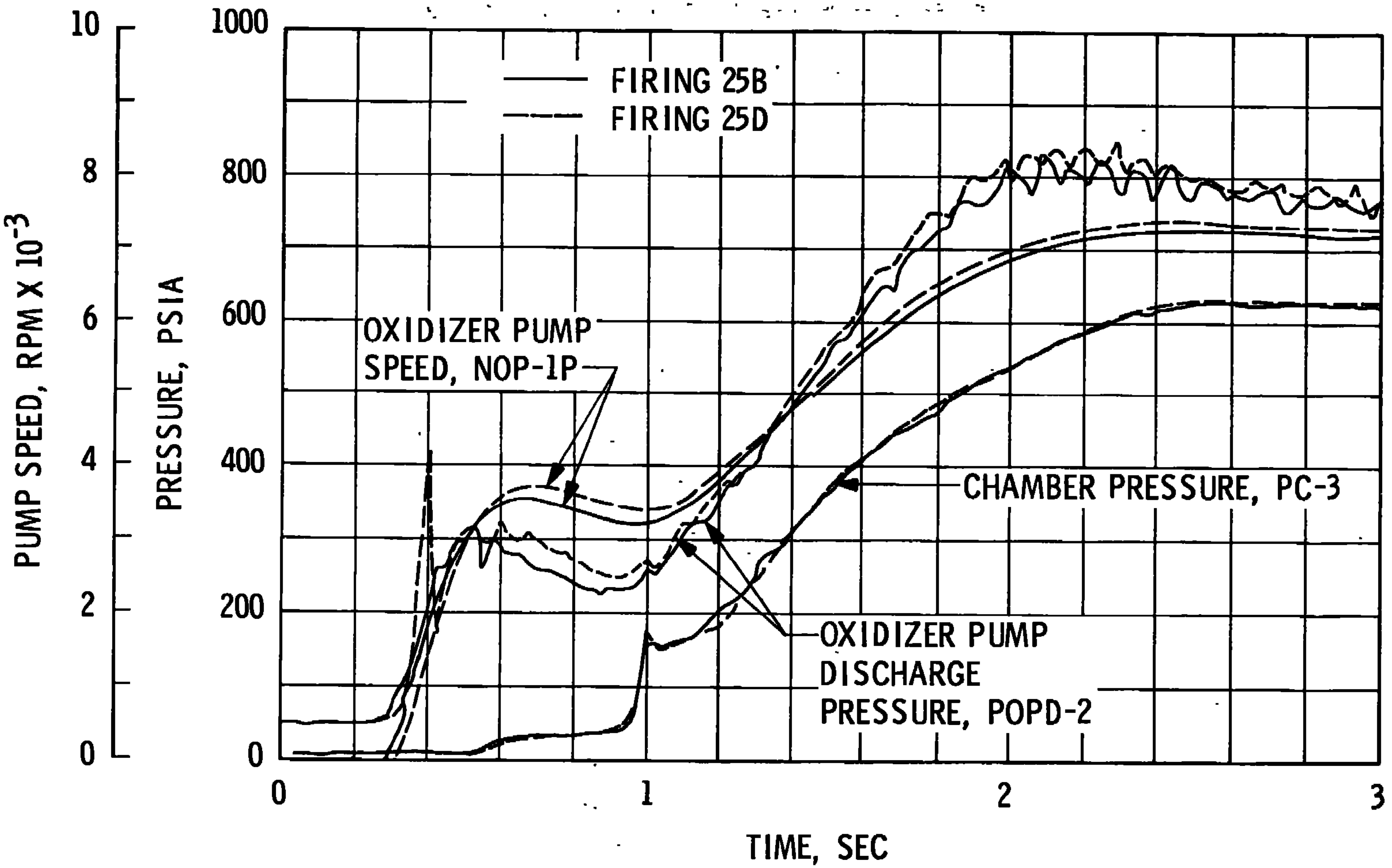


Fig. 39 Thrust Chamber Oxidizer System Start Transient Operation, Firings 25B and 25D

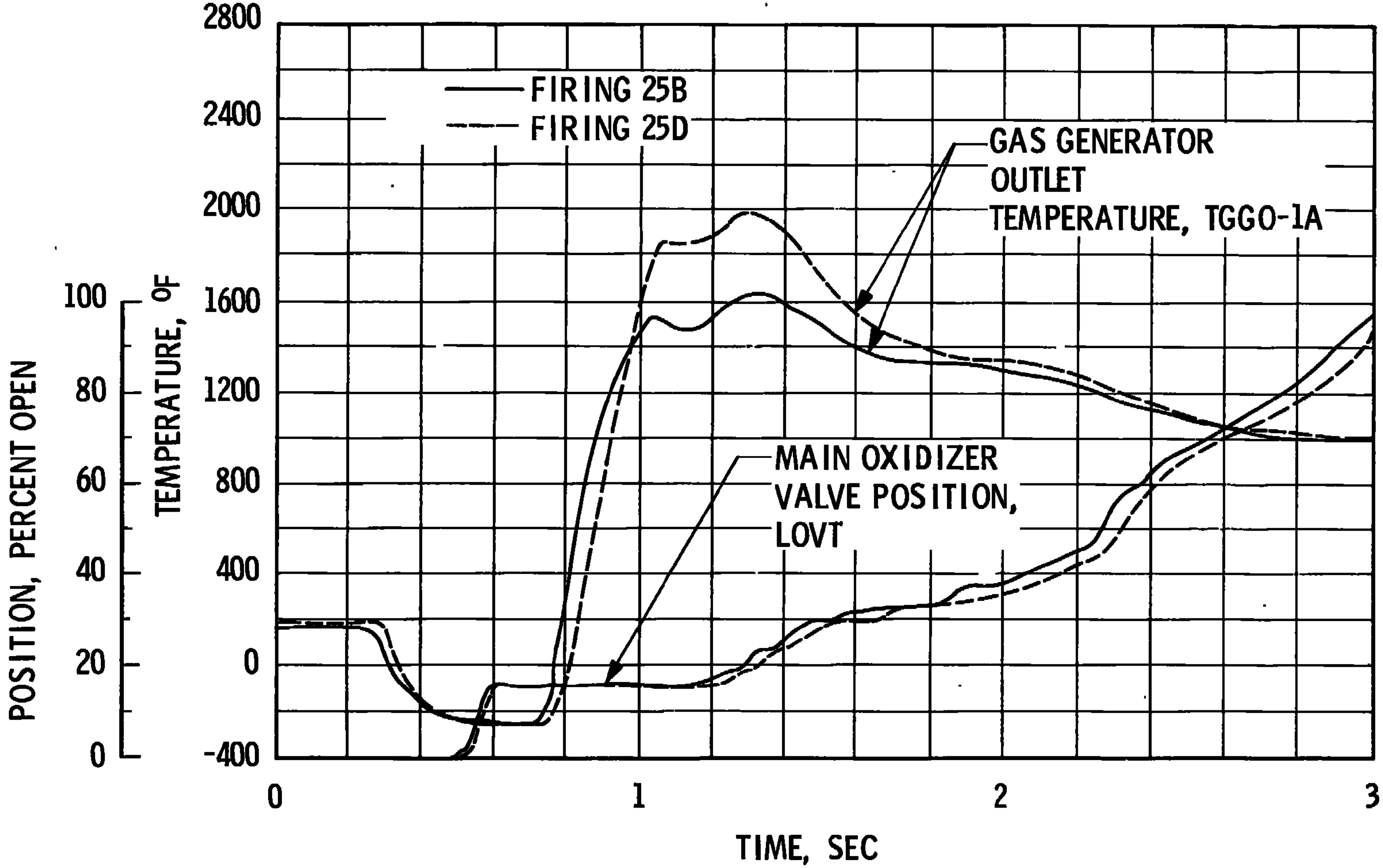


Fig. 40 Gas Generator Temperature and Main Oxidizer Valve Start Transient Operation, Firings 25B and 25D

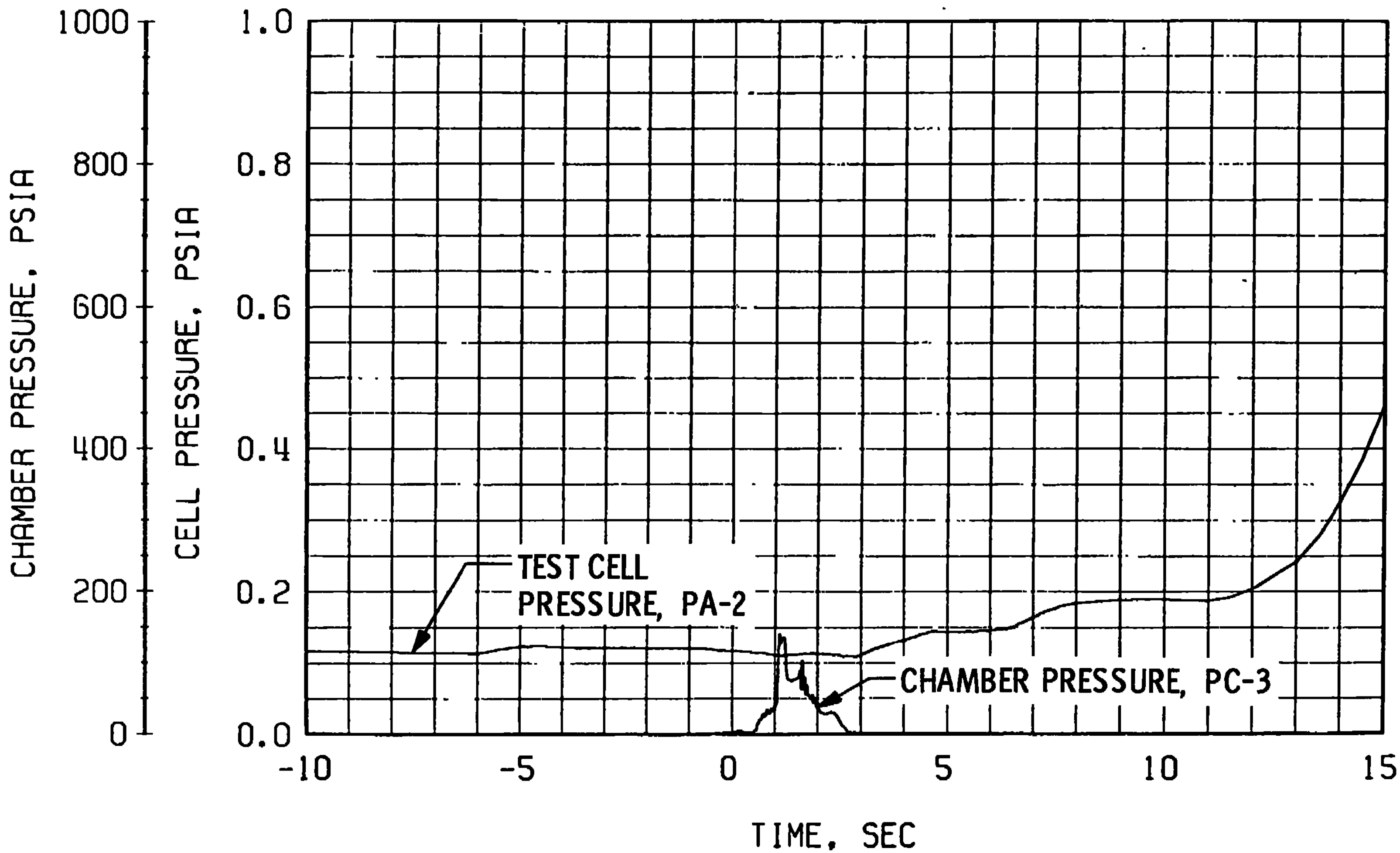
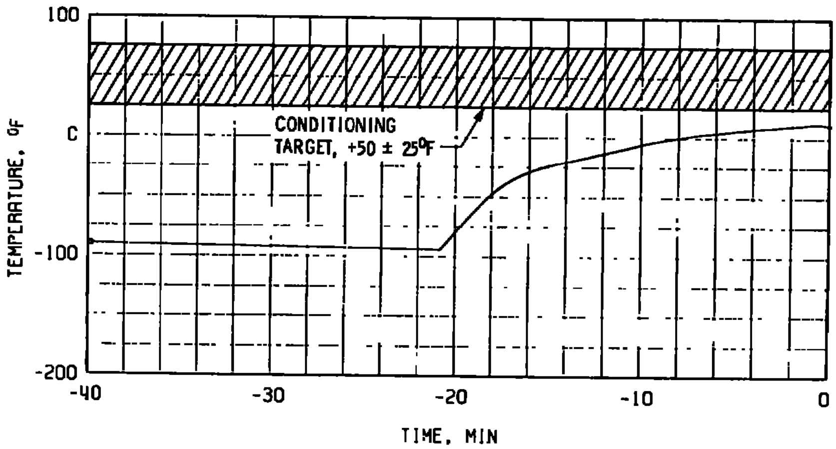
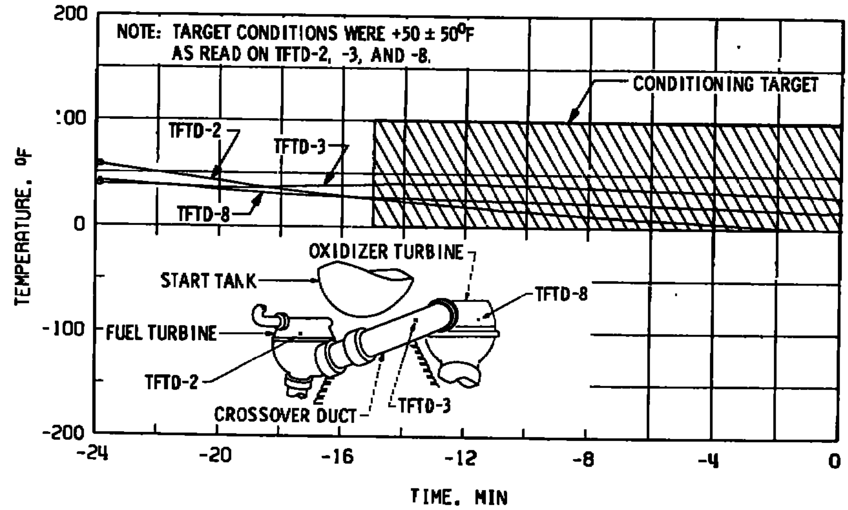


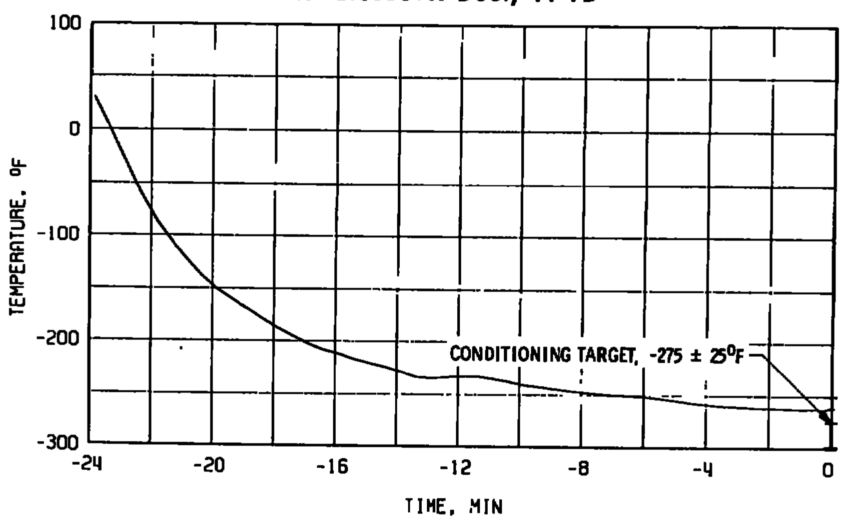
Fig. 41 Engine Ambient and Combustion Chamber Pressures, Firing 25E



a. Start Tank Discharge Valve, TSTDVOC

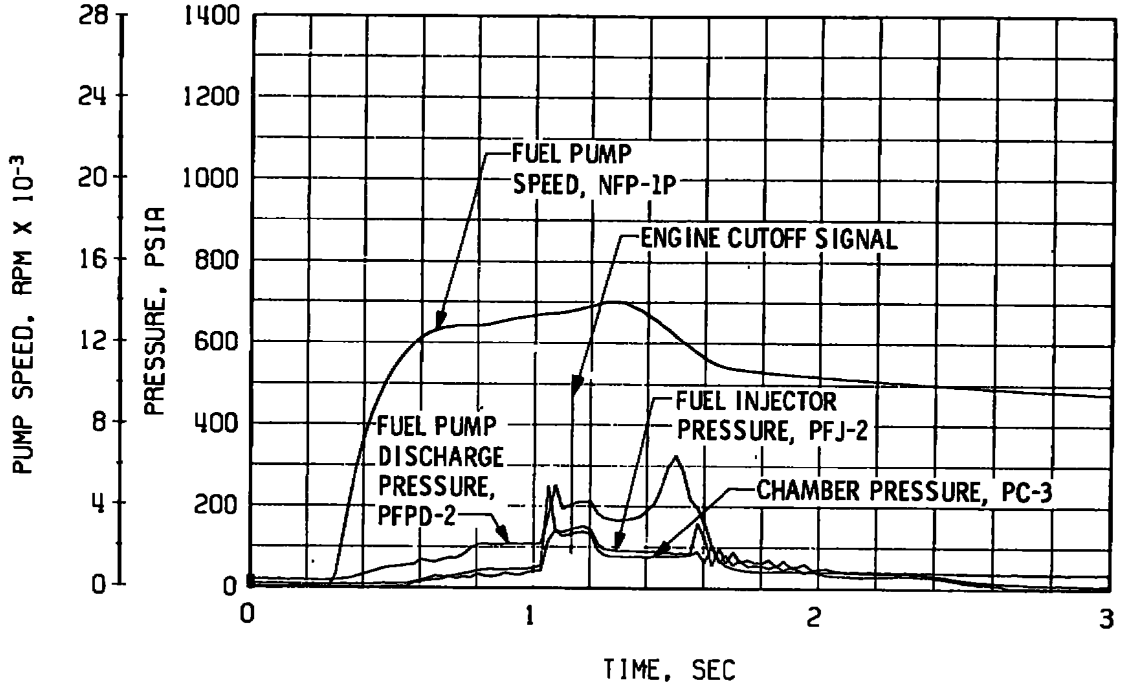


b. Crossover Duct, TFTD

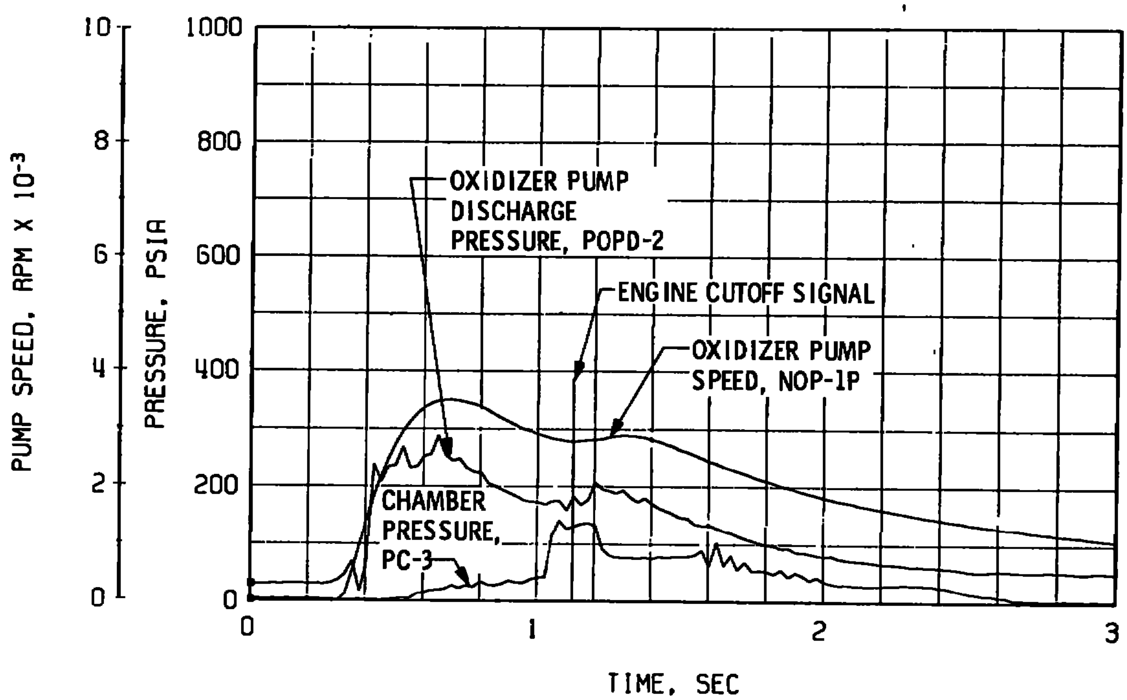


c. Thrust Chamber Throat, TTC-1P

Fig. 42 Thermal Conditioning History of Engine Components, Firing 25E

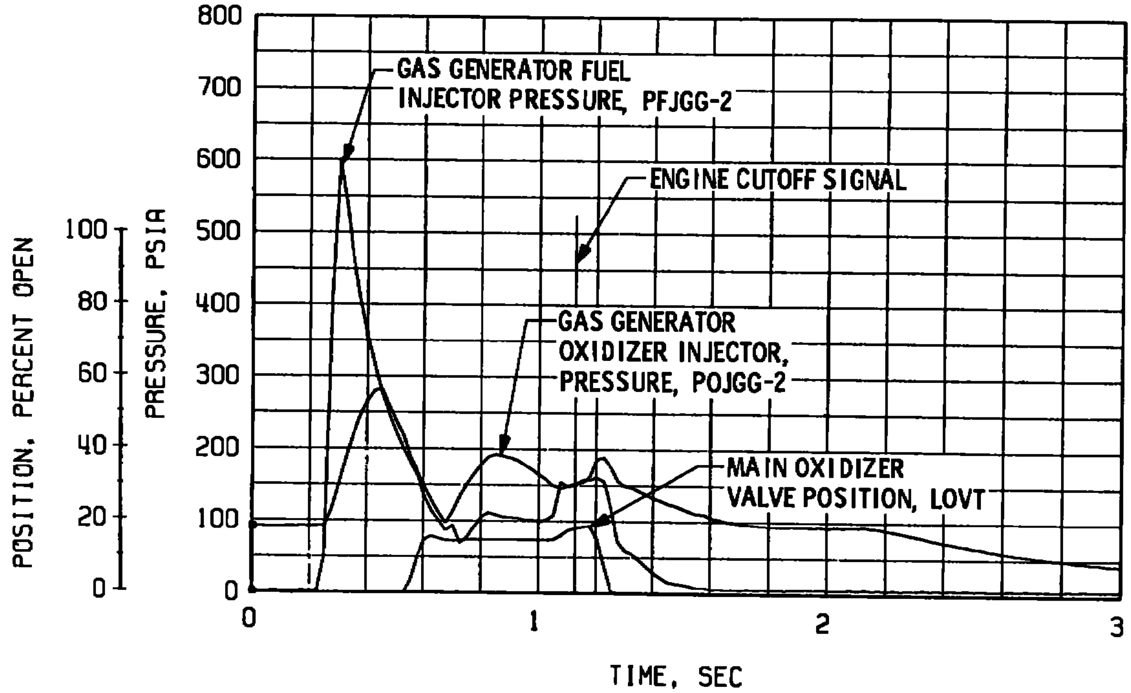


a. Thrust Chamber Fuel System, Start and Shutdown

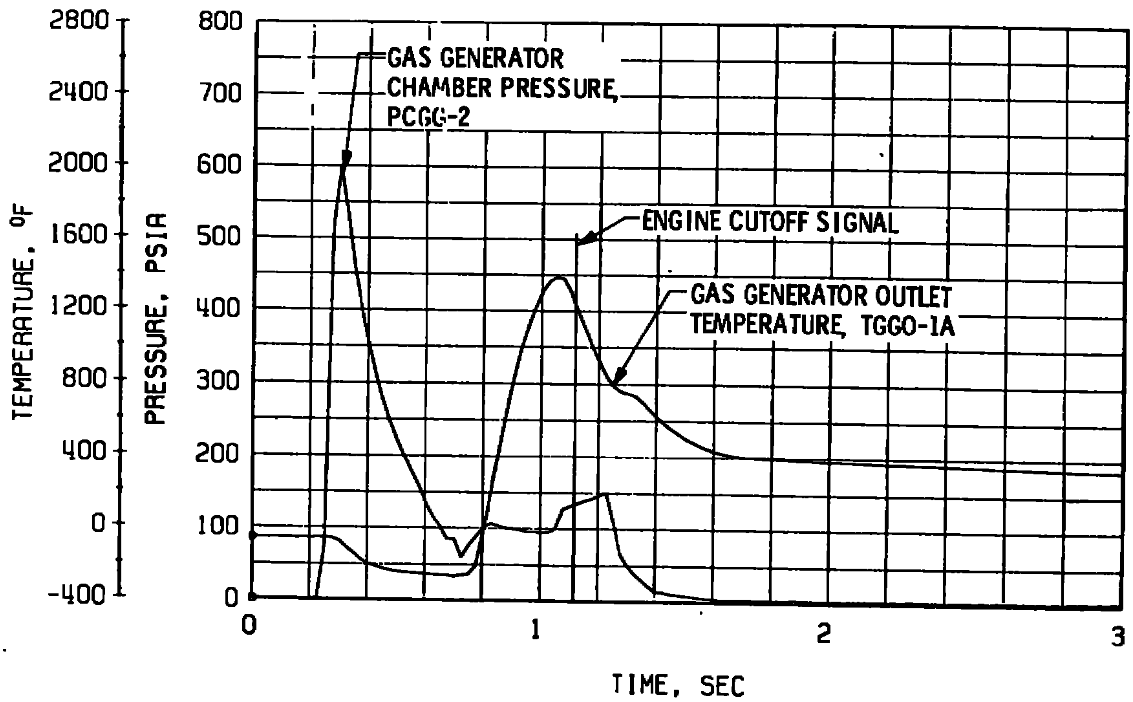


b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 43 Engine Transient Operation, Firing 25E



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 43 Concluded

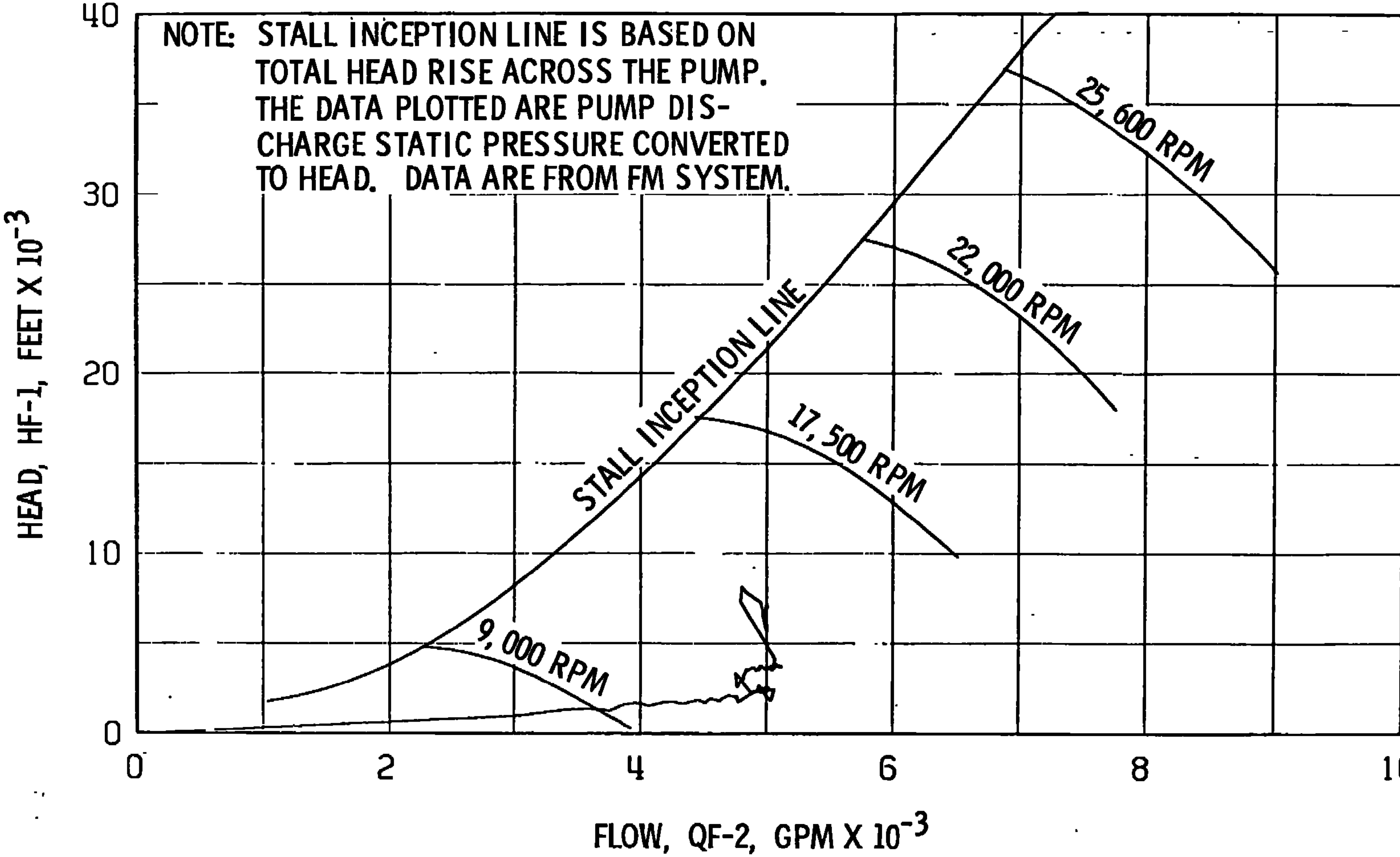


Fig. 44 Fuel Pump Start Transient Performance, Firing 25E

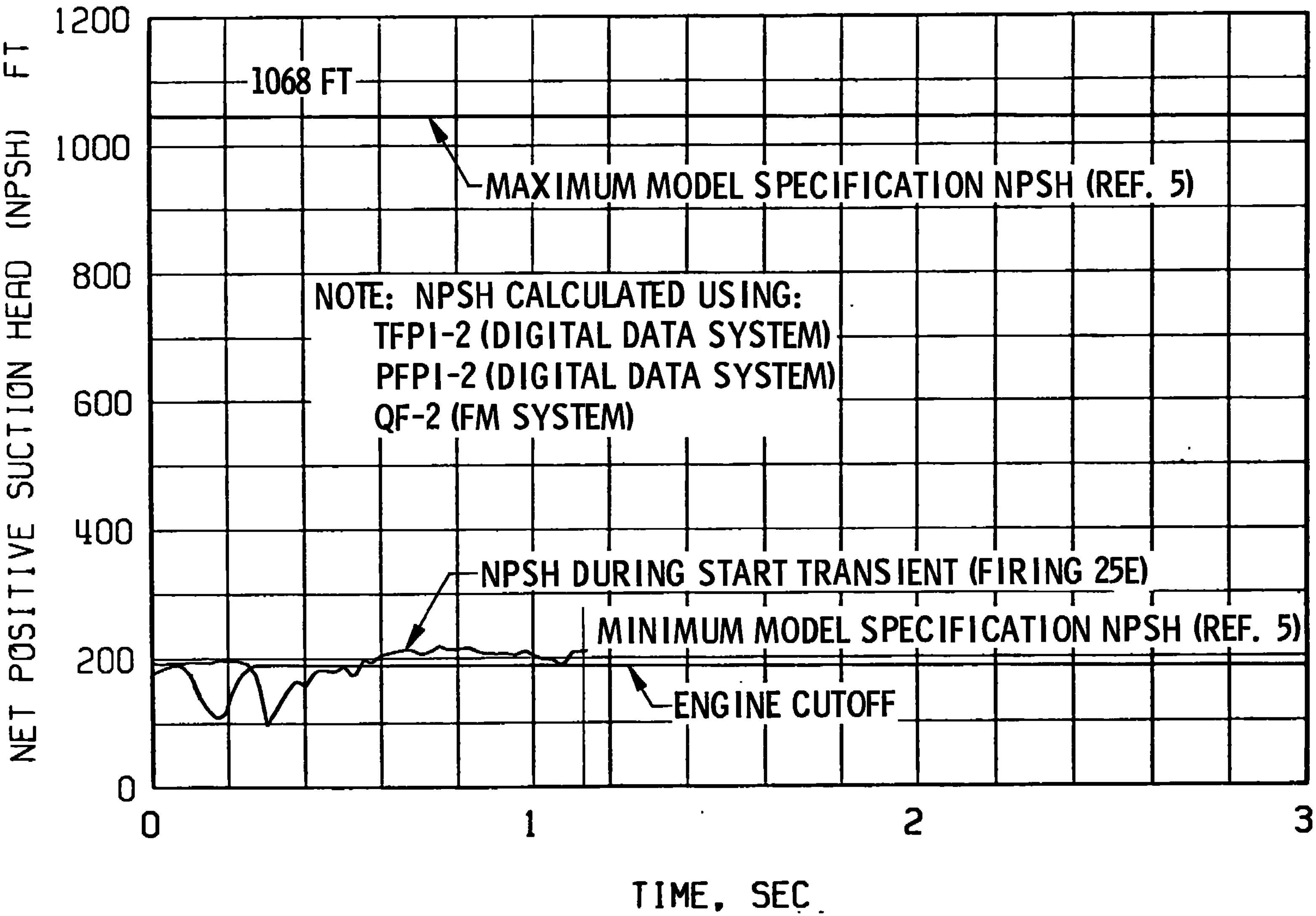
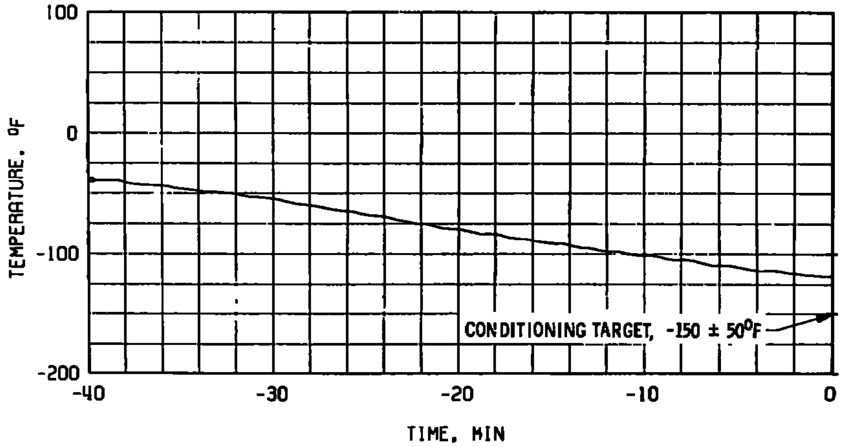
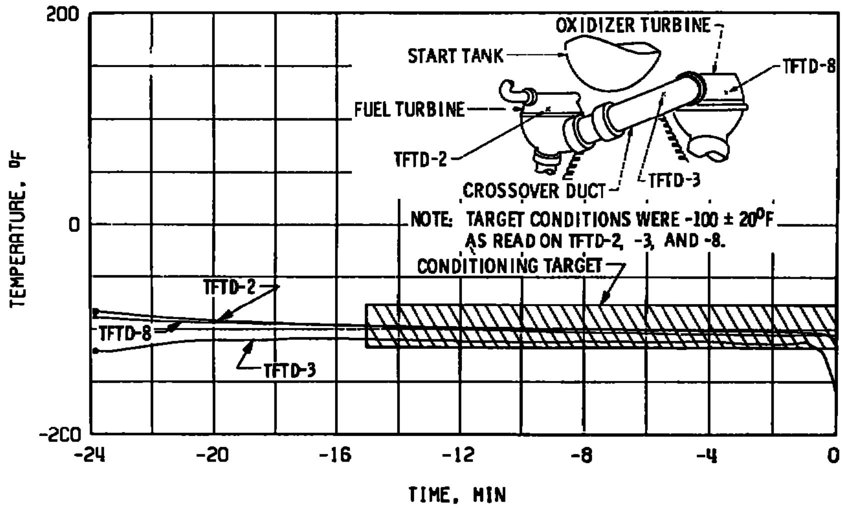


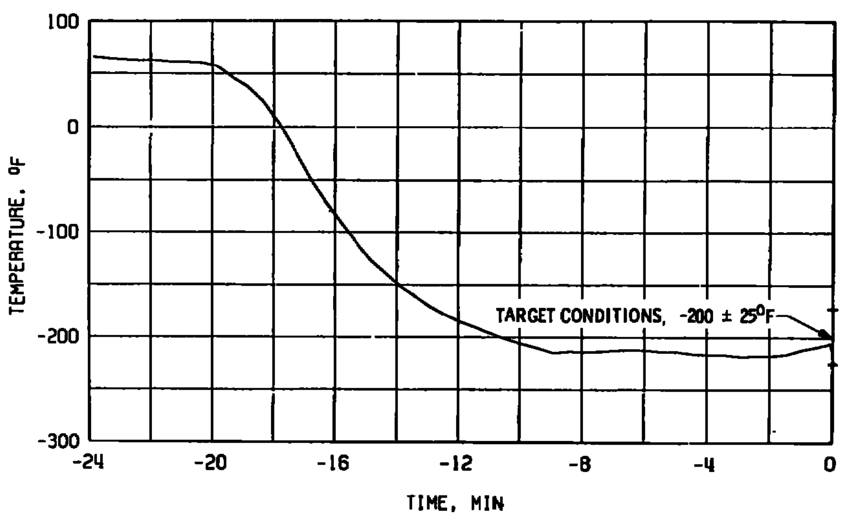
Fig. 45 Fuel Pump Net Positive Suction Head during Start Transient, Firing 25E



a. Main Oxidizer Valve Second- Stage Actuator, TSOVC-1



b. Crossover Duct, TFTD



c. Thrust Chamber Throat, TTC-1P

Fig. 46 Thermal Conditioning History of Engine Components, Firing 26A

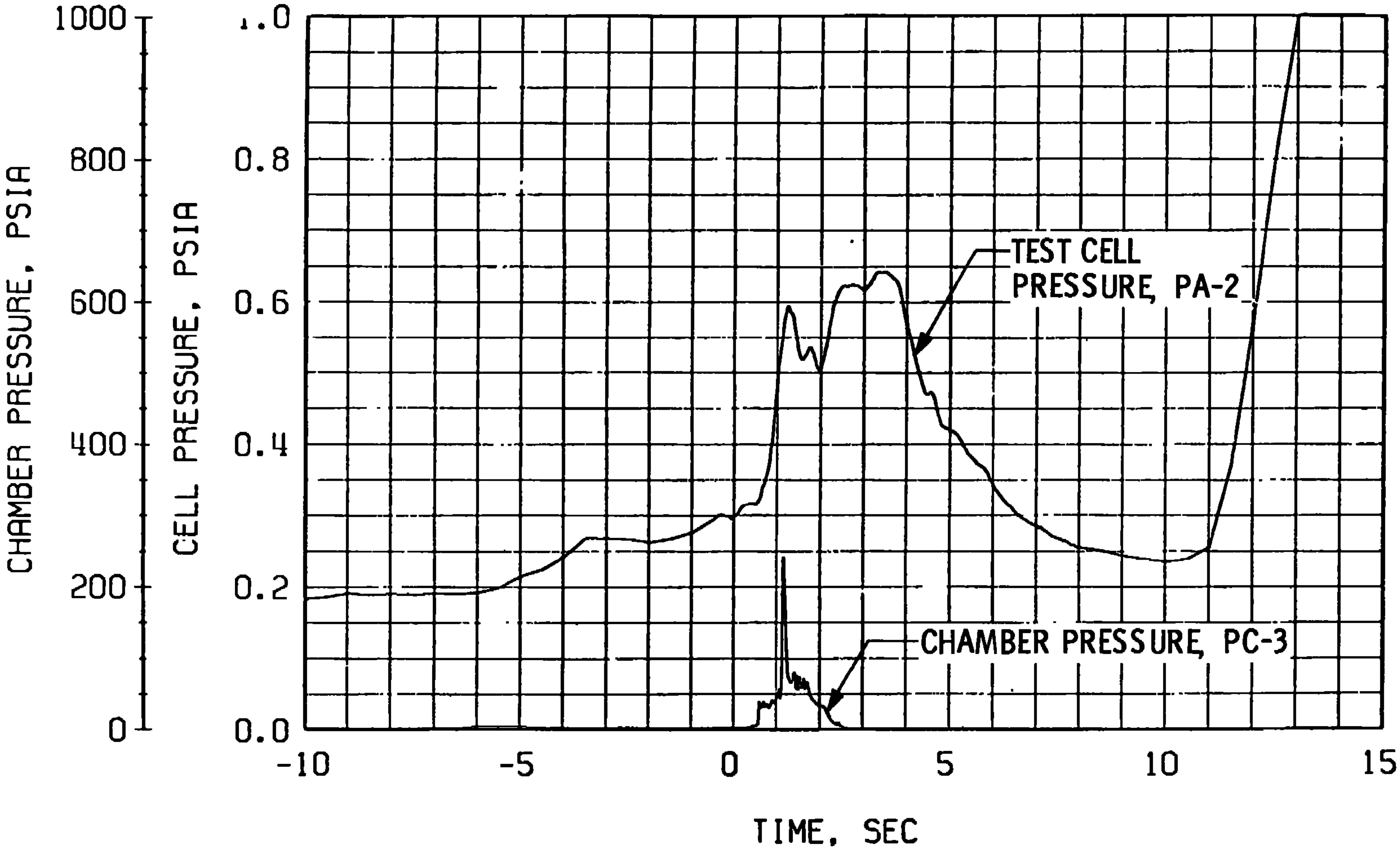
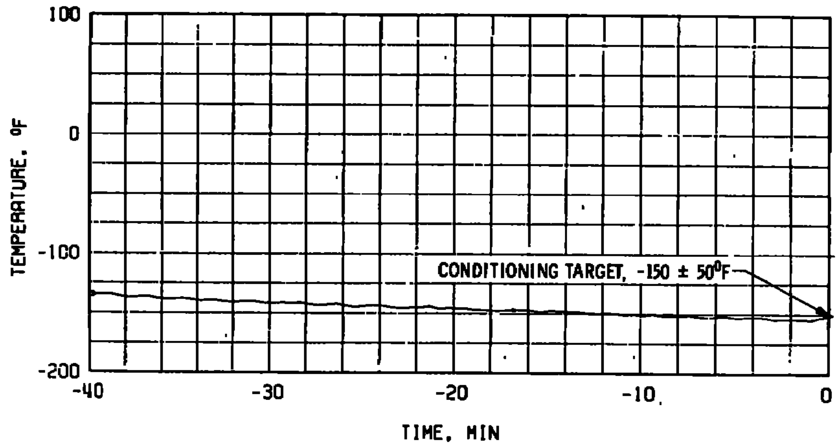
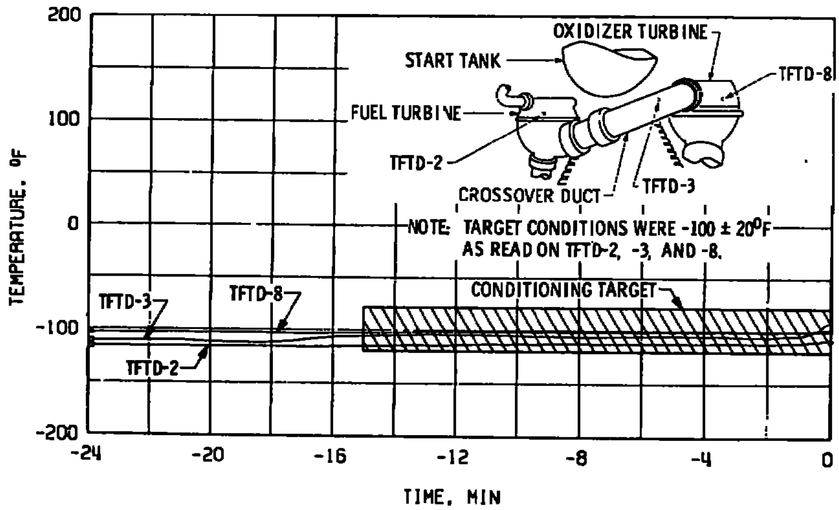


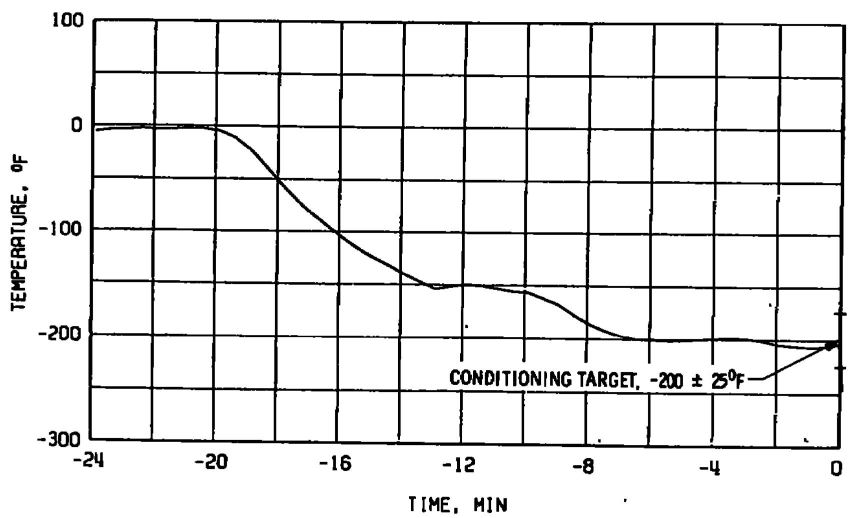
Fig. 47 Engine Ambient and Combustion Chamber Pressures, Firing 26A



a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

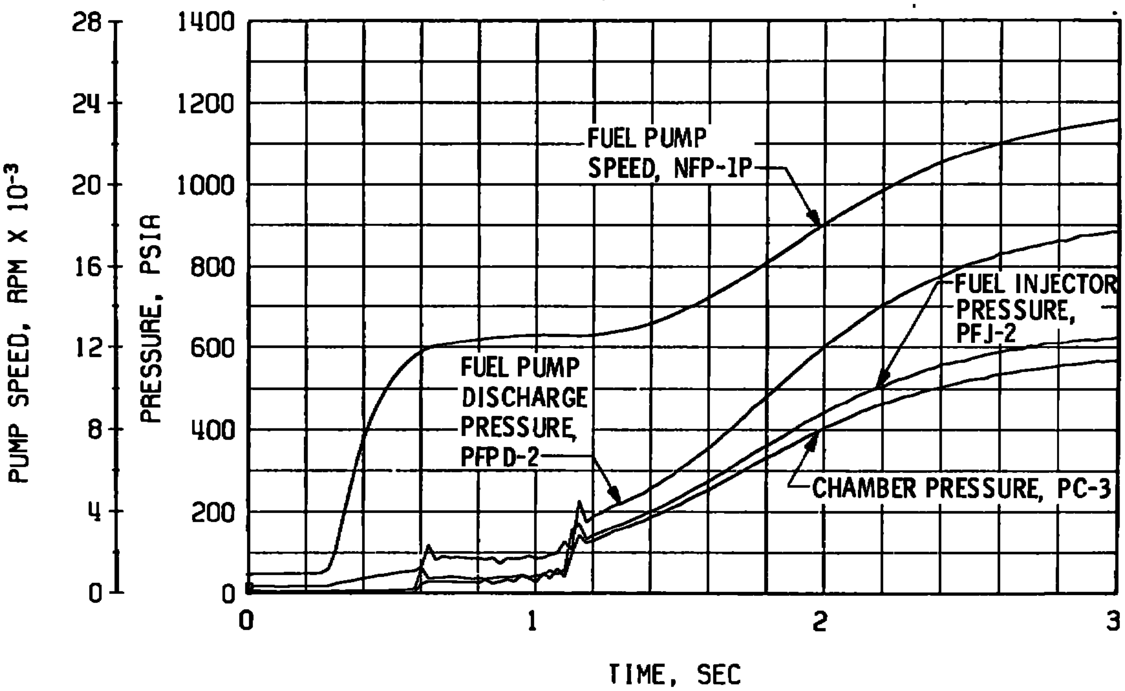


b. Crossover Duct, TFTD

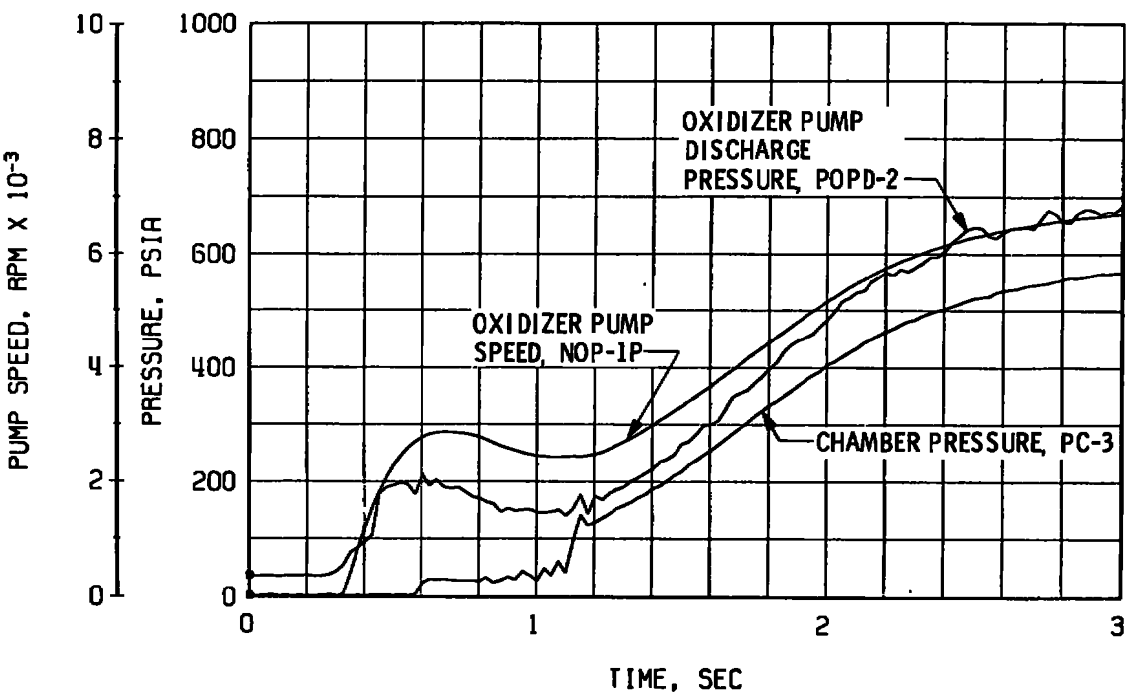


c. Thrust Chamber Throat, TTC-1P

Fig. 48 Thermal Conditioning History of Engine Components, Firing 26AA

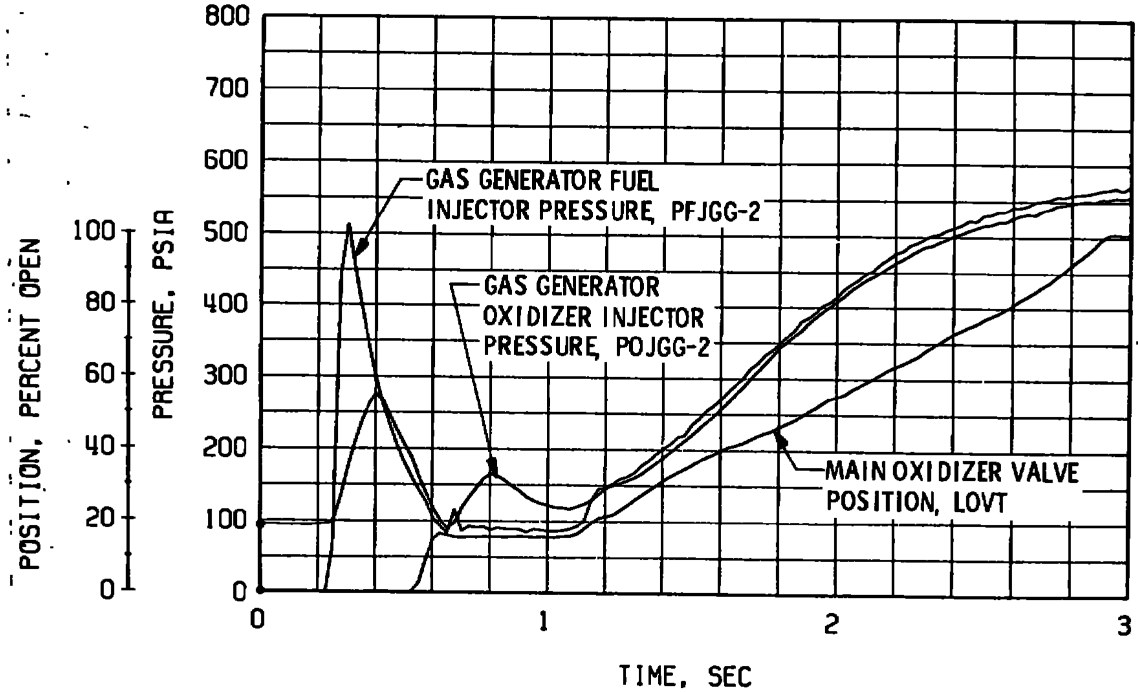


a. Thrust Chamber Fuel System, Start

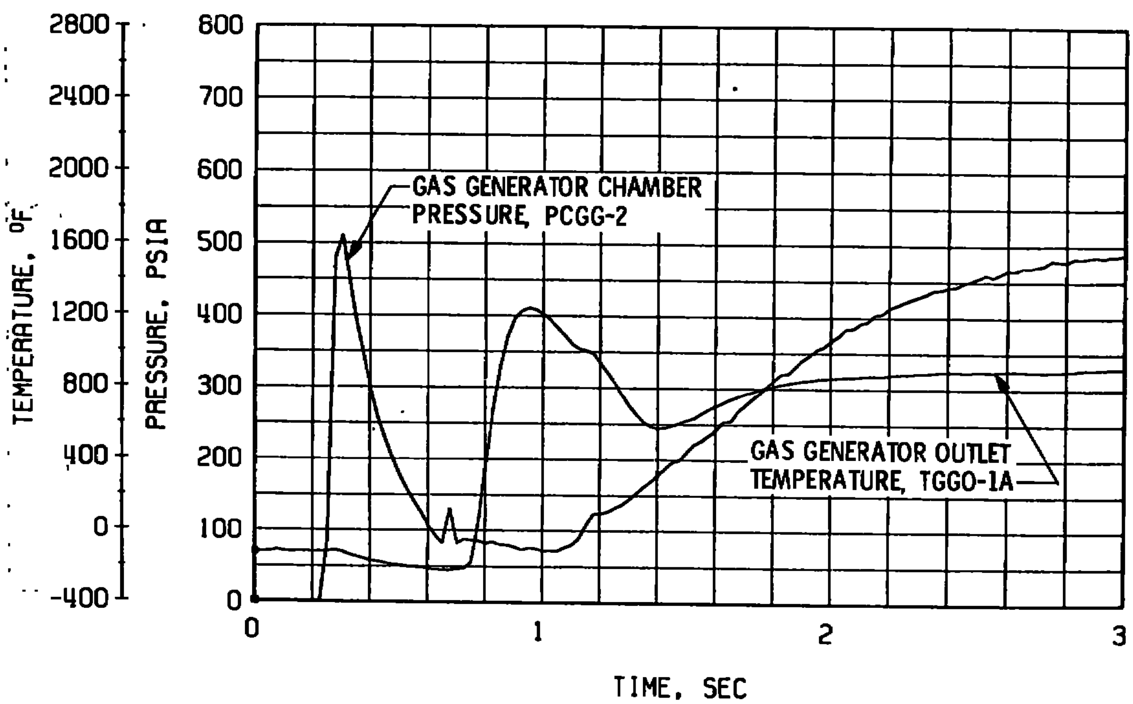


b. Thrust Chamber Oxidizer System, Start

Fig. 49 Engine Transient Operation, Firing 26AA

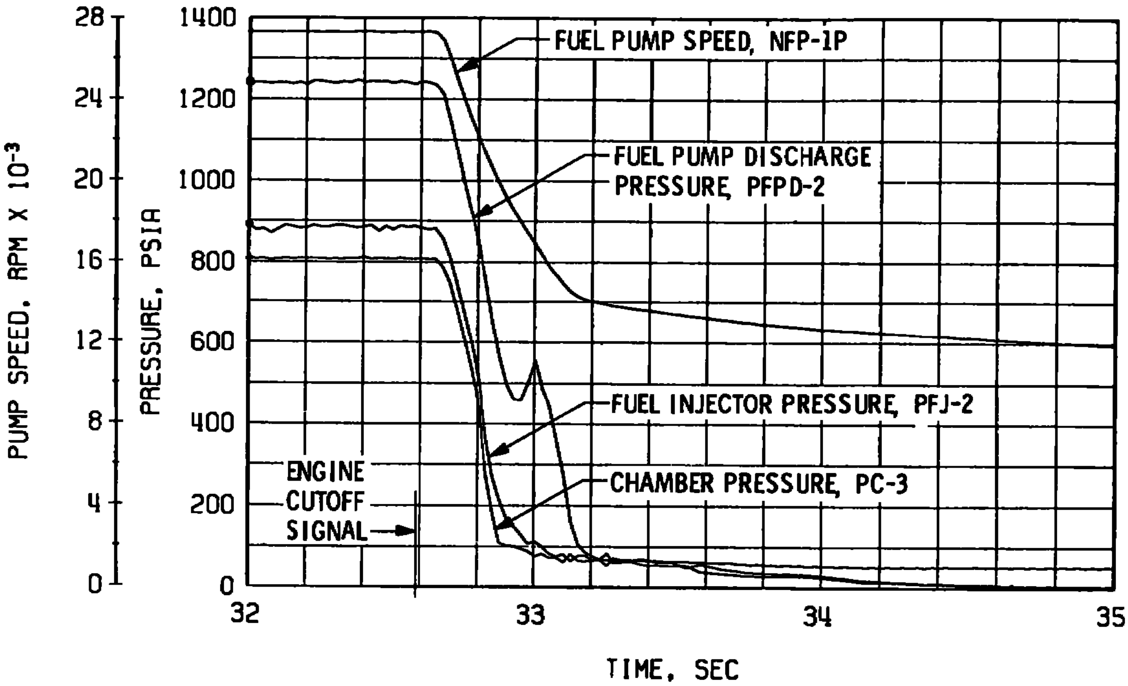


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

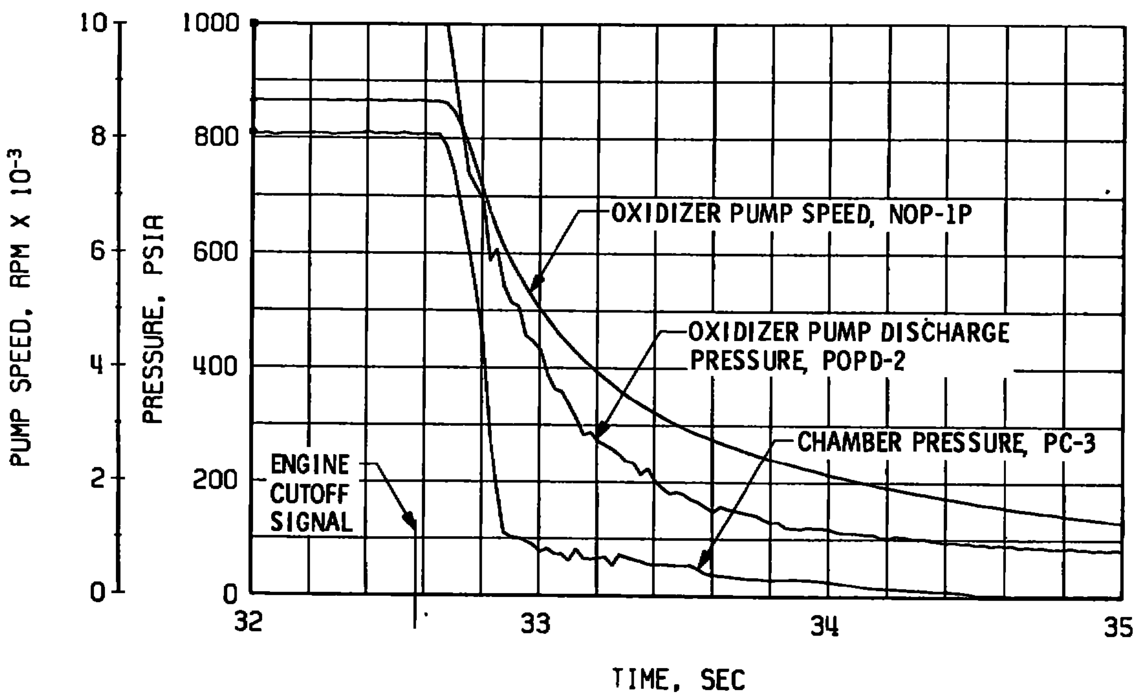


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 49 Continued

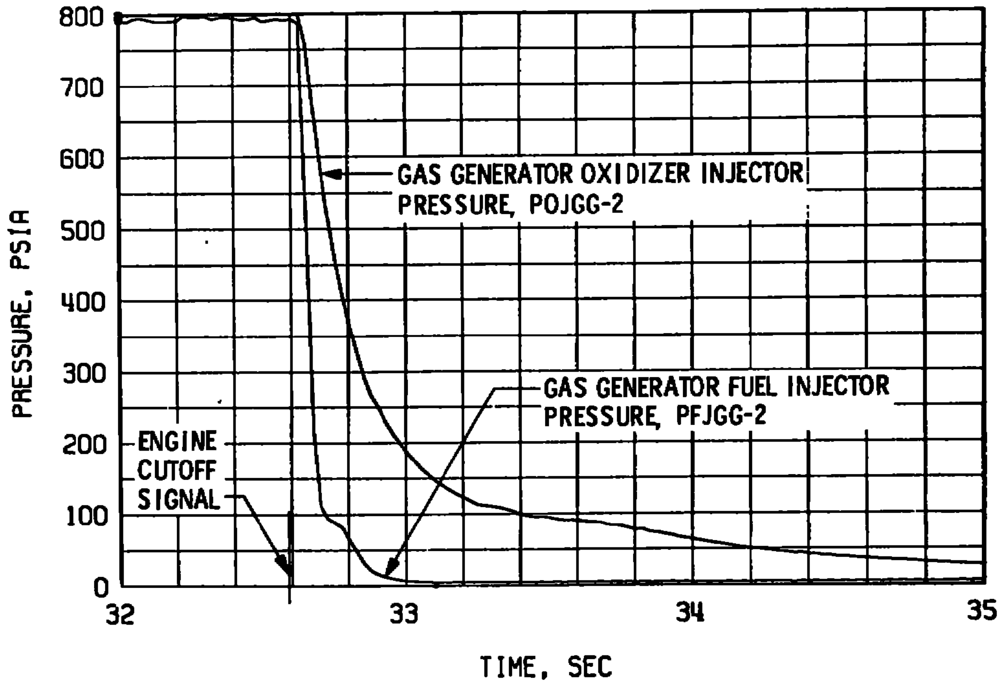


e. Thrust Chamber Fuel System, Shutdown

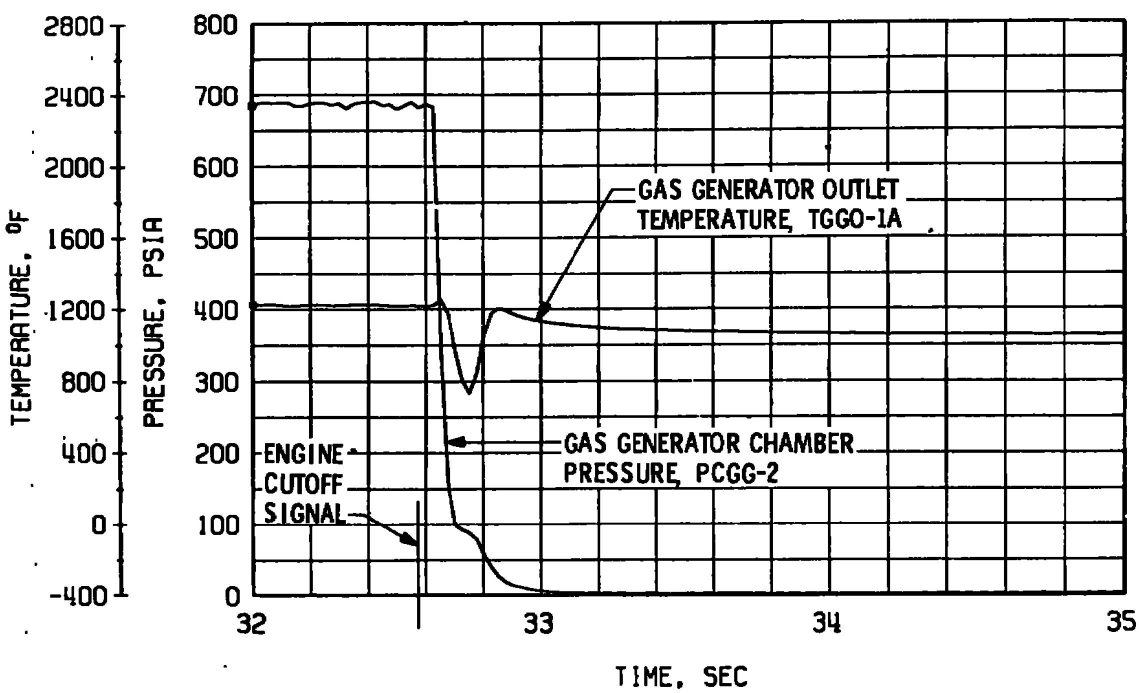


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 49 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 49 Concluded

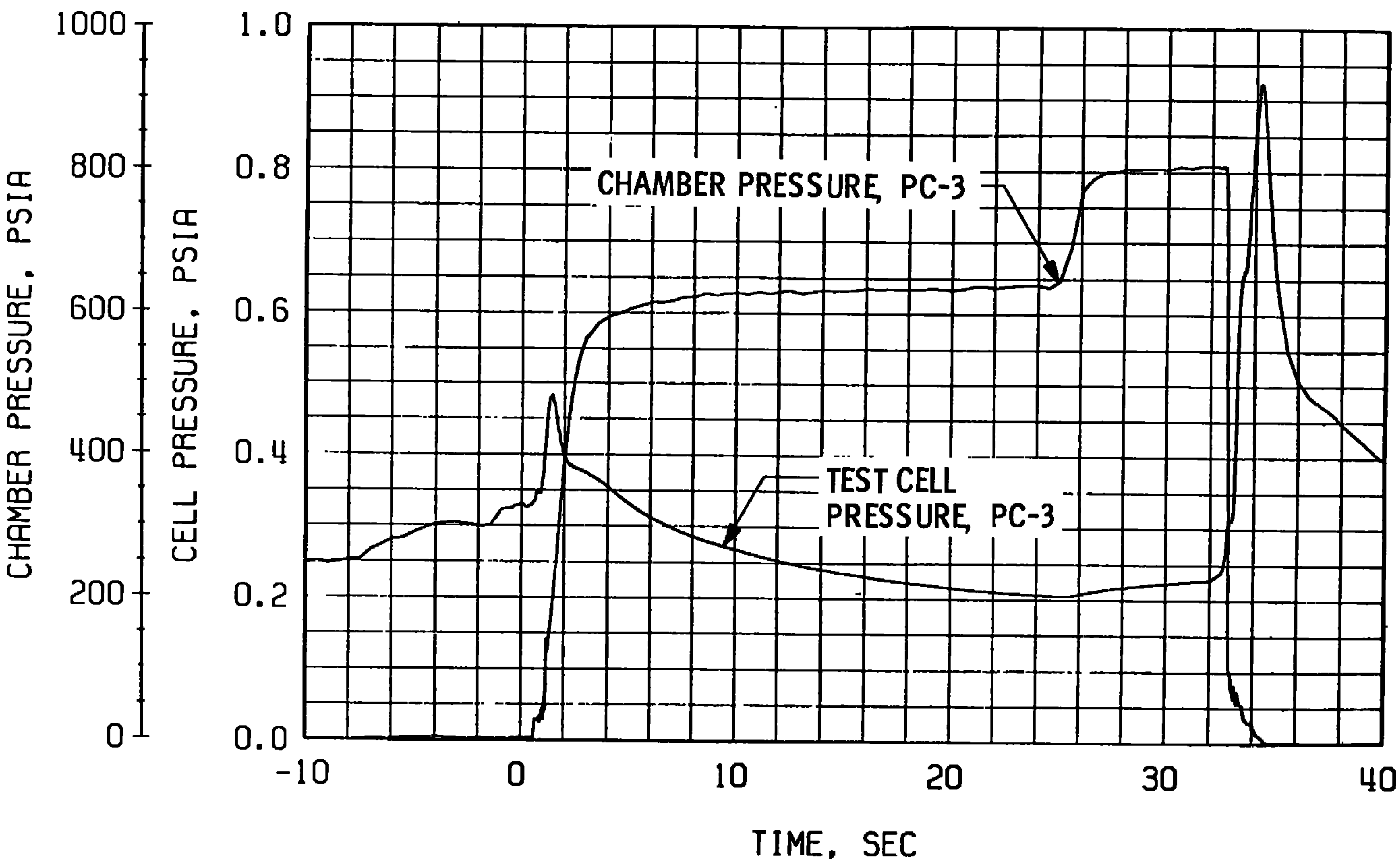


Fig. 50 Engine Ambient and Combustion Chamber Pressures, Firing 26AA

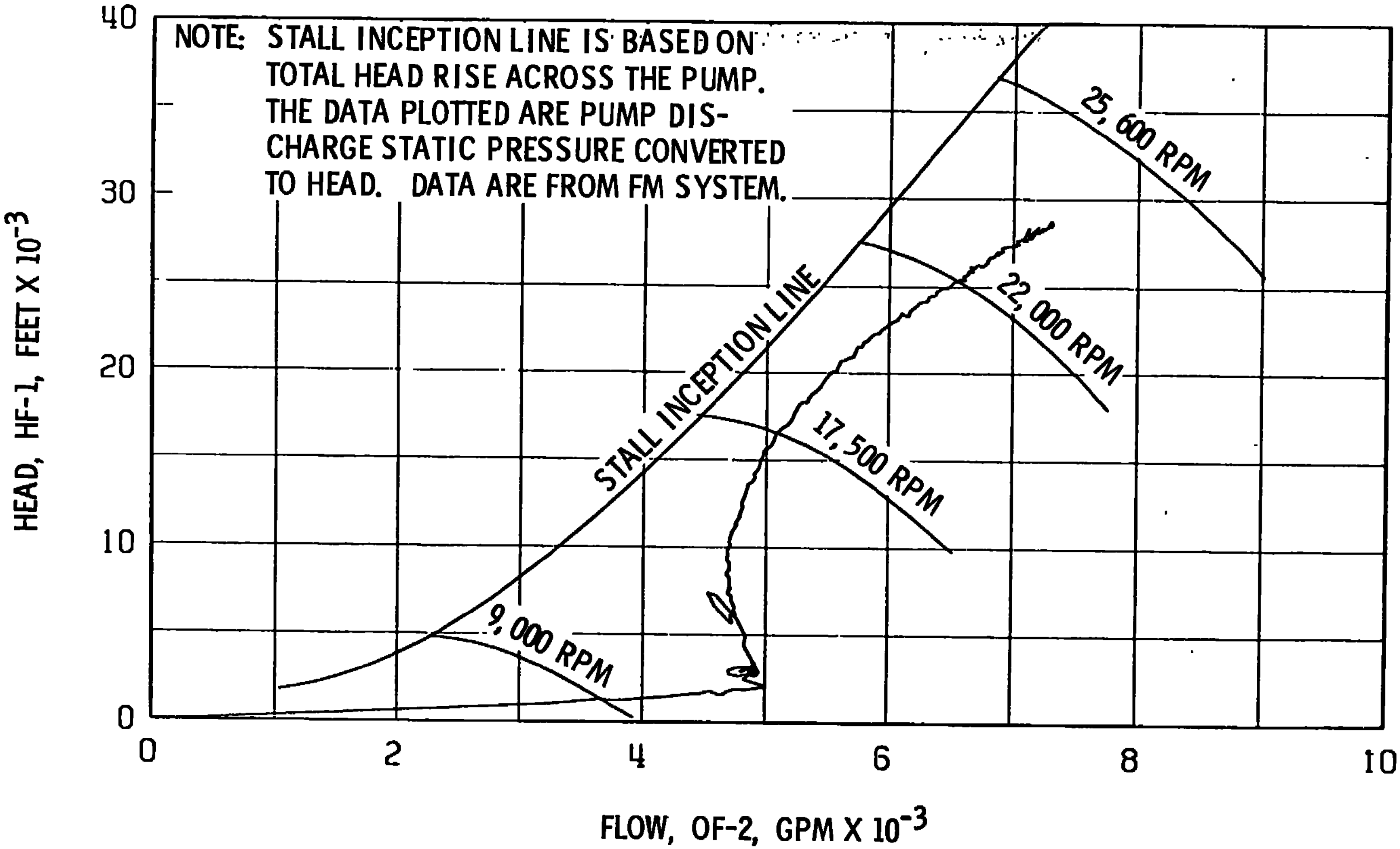
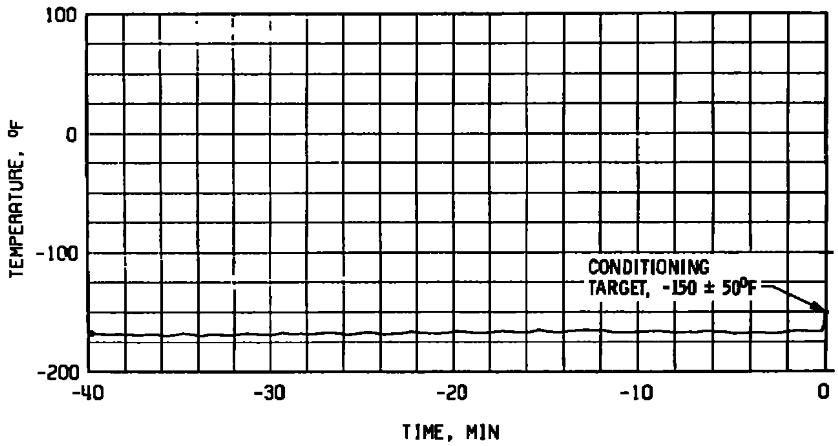
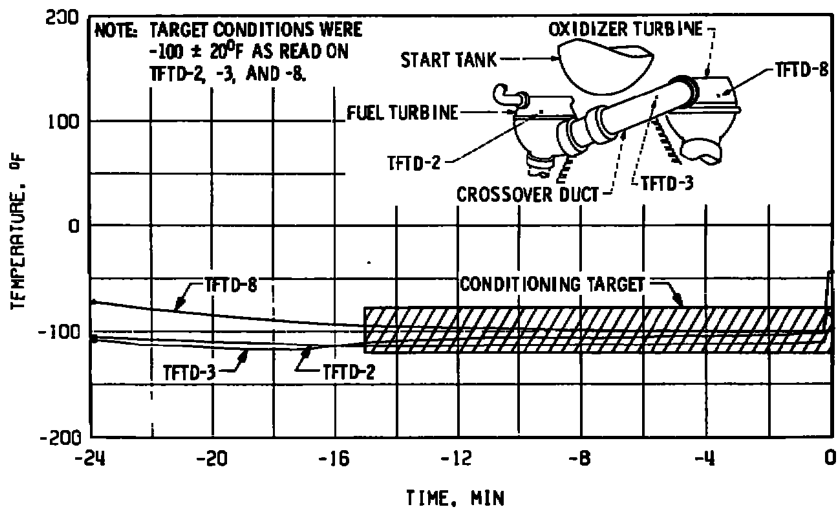


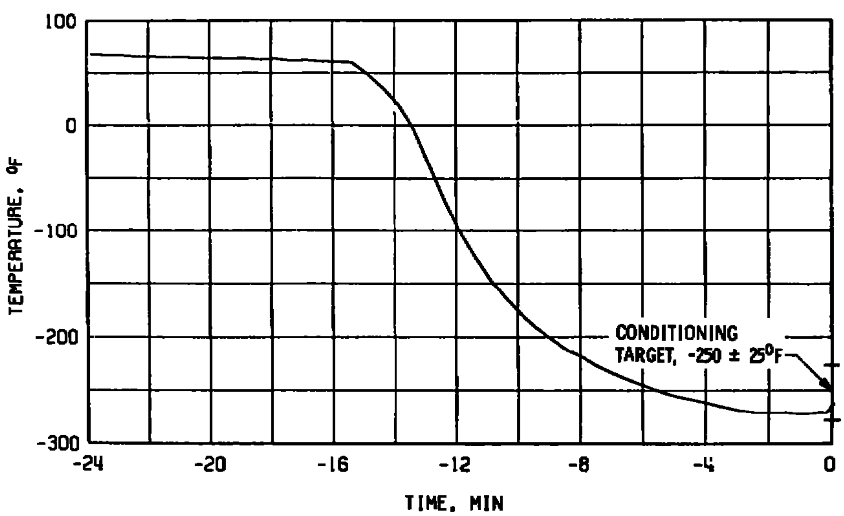
Fig. 51 Fuel Pump Start Transient Performance, Firing 26AA



a. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

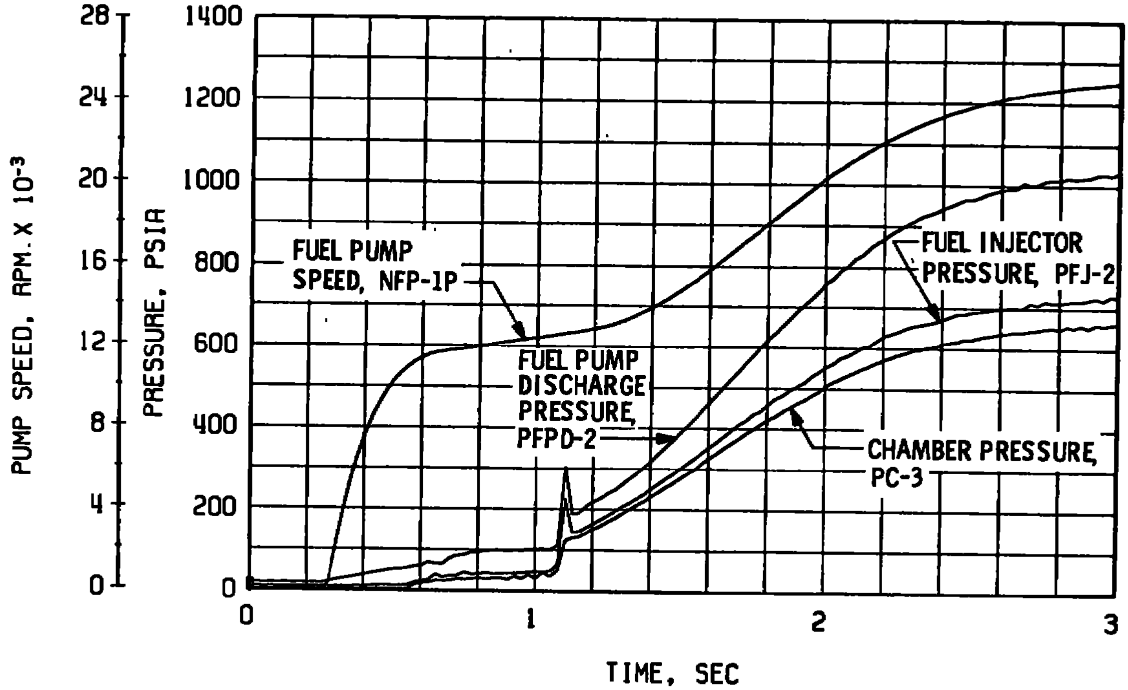


b. Crossover Duct, TFTD

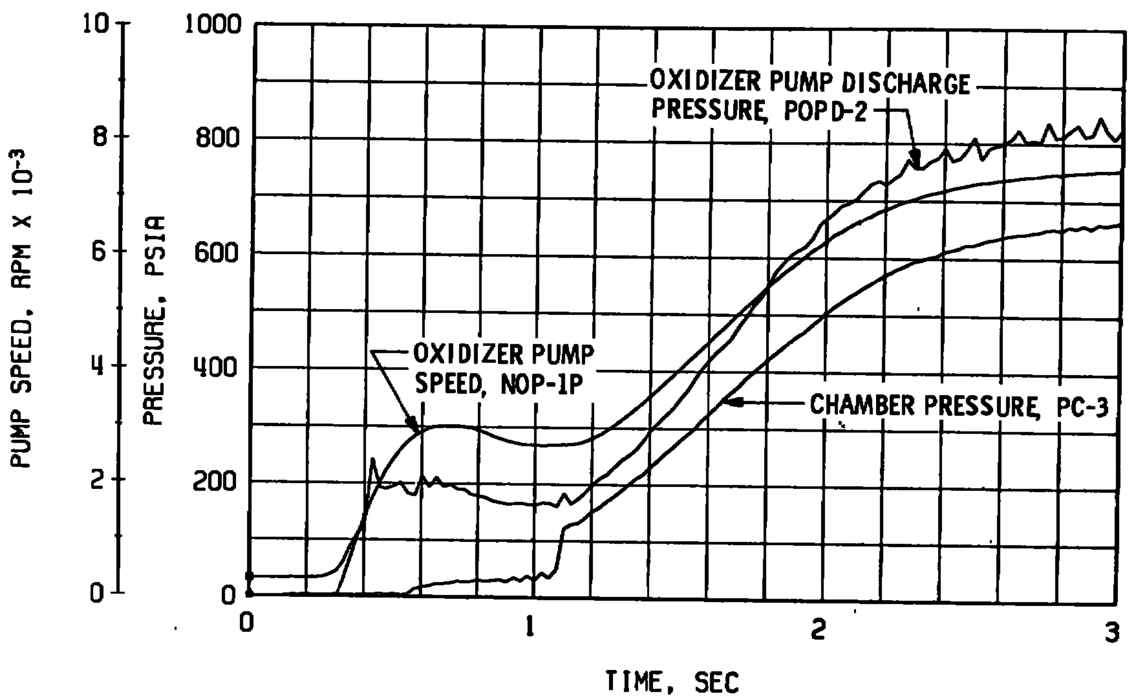


c. Thrust Chamber Throat, TTC-1P

Fig. 52 Thermal Conditioning History of Engine Components, Firing 27A

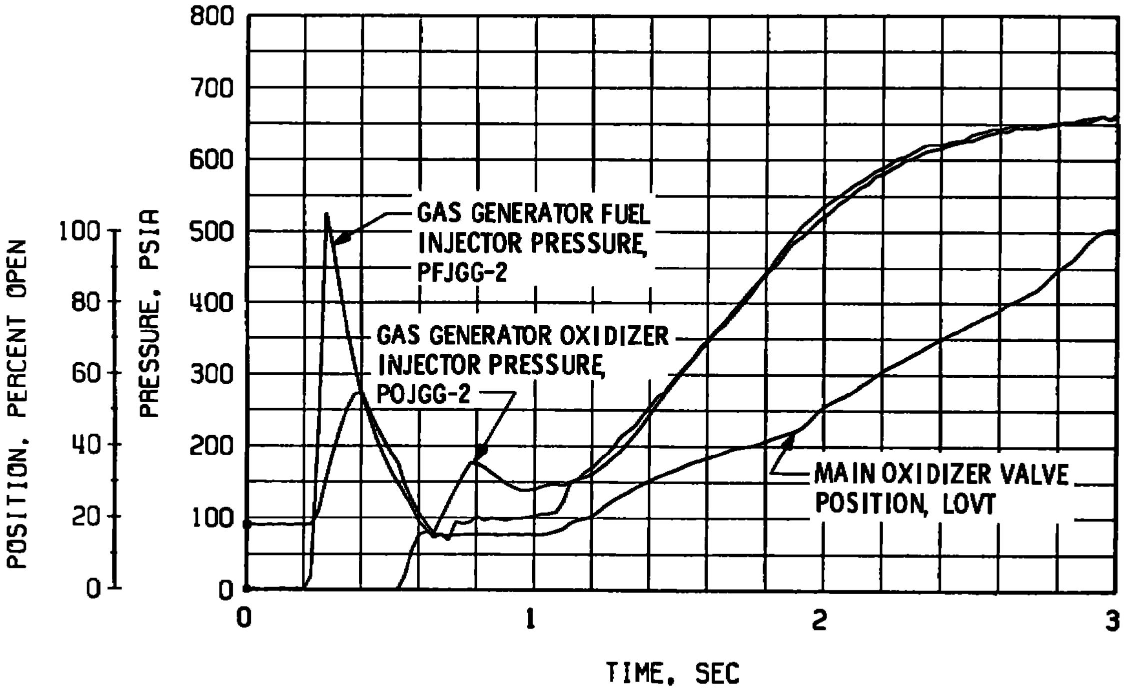


a. Thrust Chamber Fuel System, Start

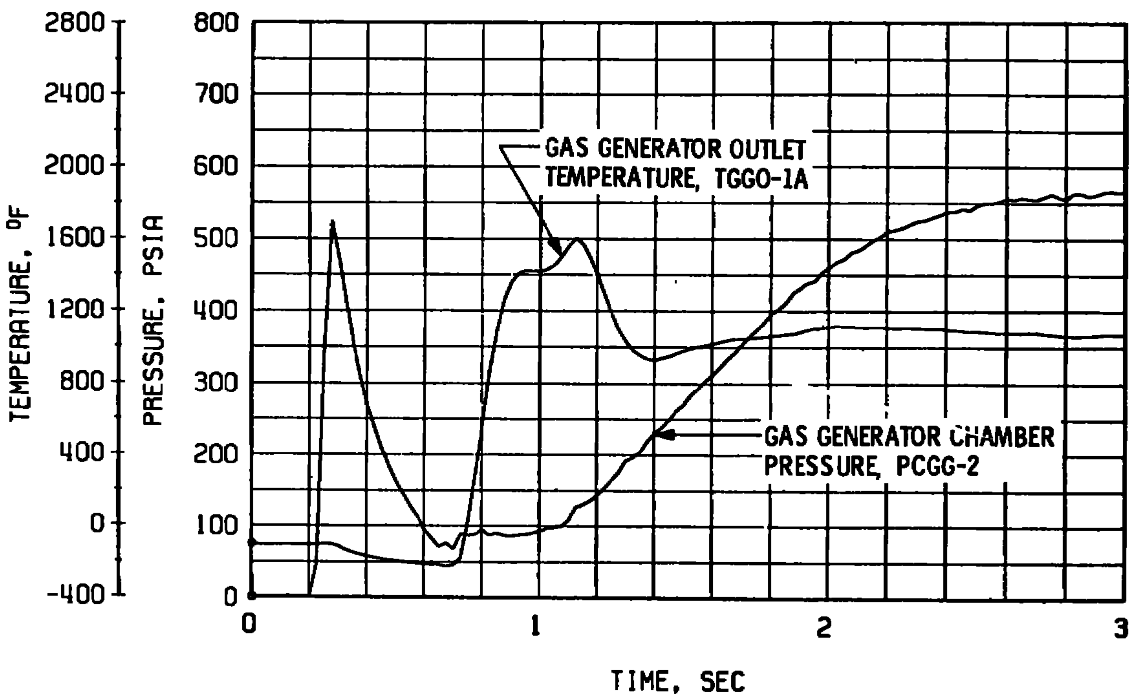


b. Thrust Chamber Oxidizer System, Start

Fig. 53 Engine Transient Operation, Firing 27A

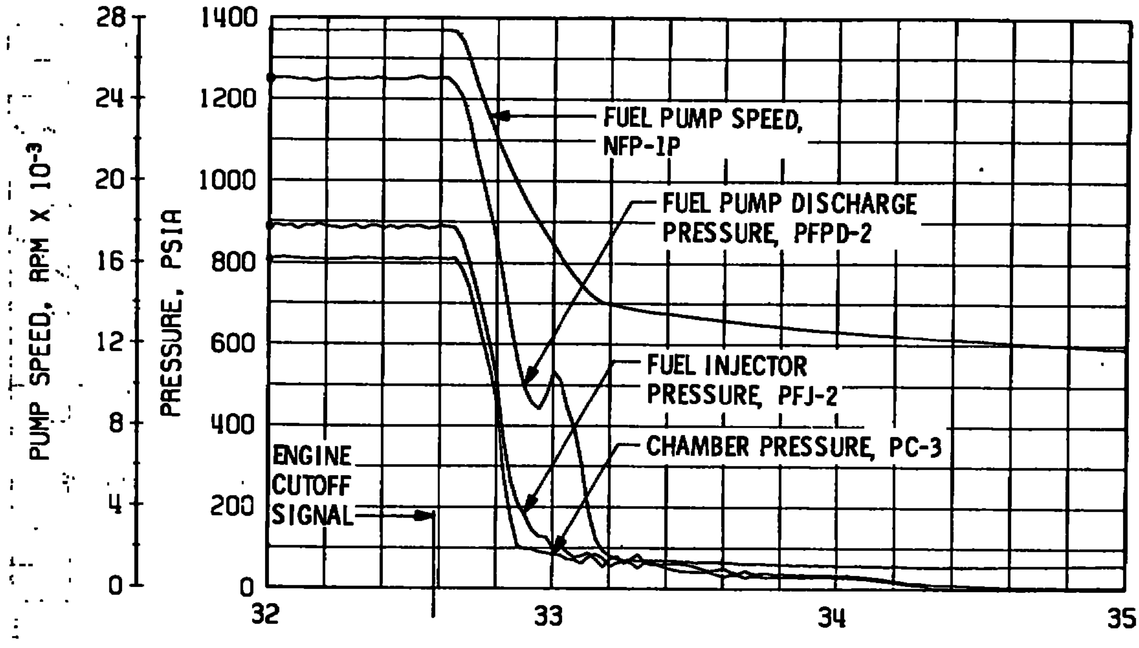


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

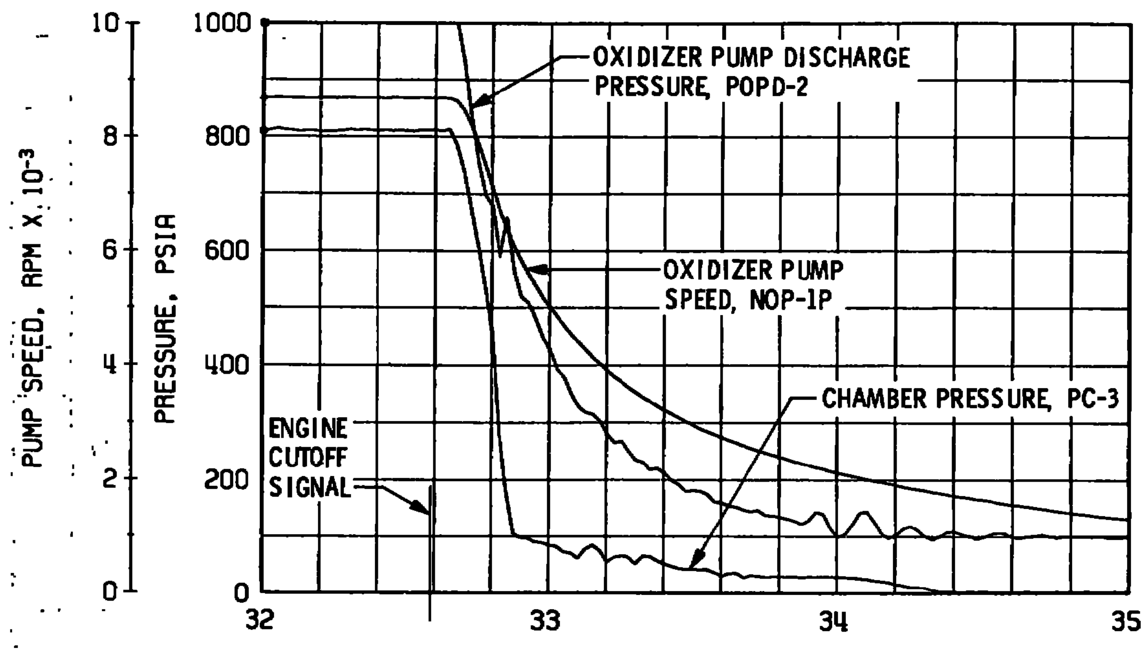


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 53 Continued

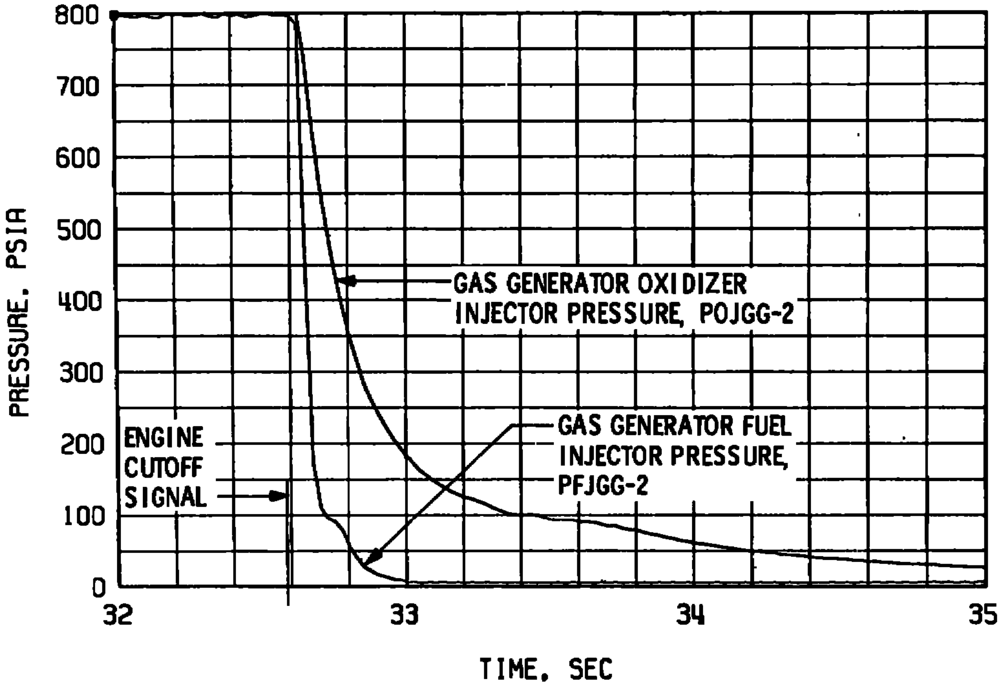


e. Thrust Chamber Fuel System, Shutdown

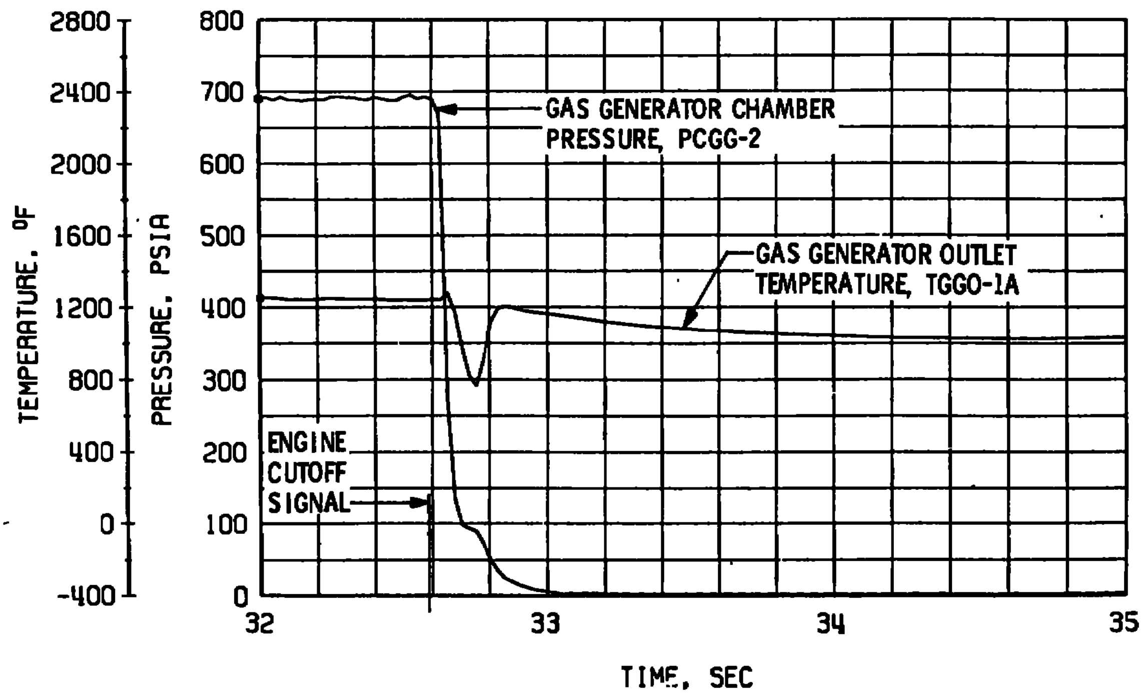


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 53 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 53 Concluded

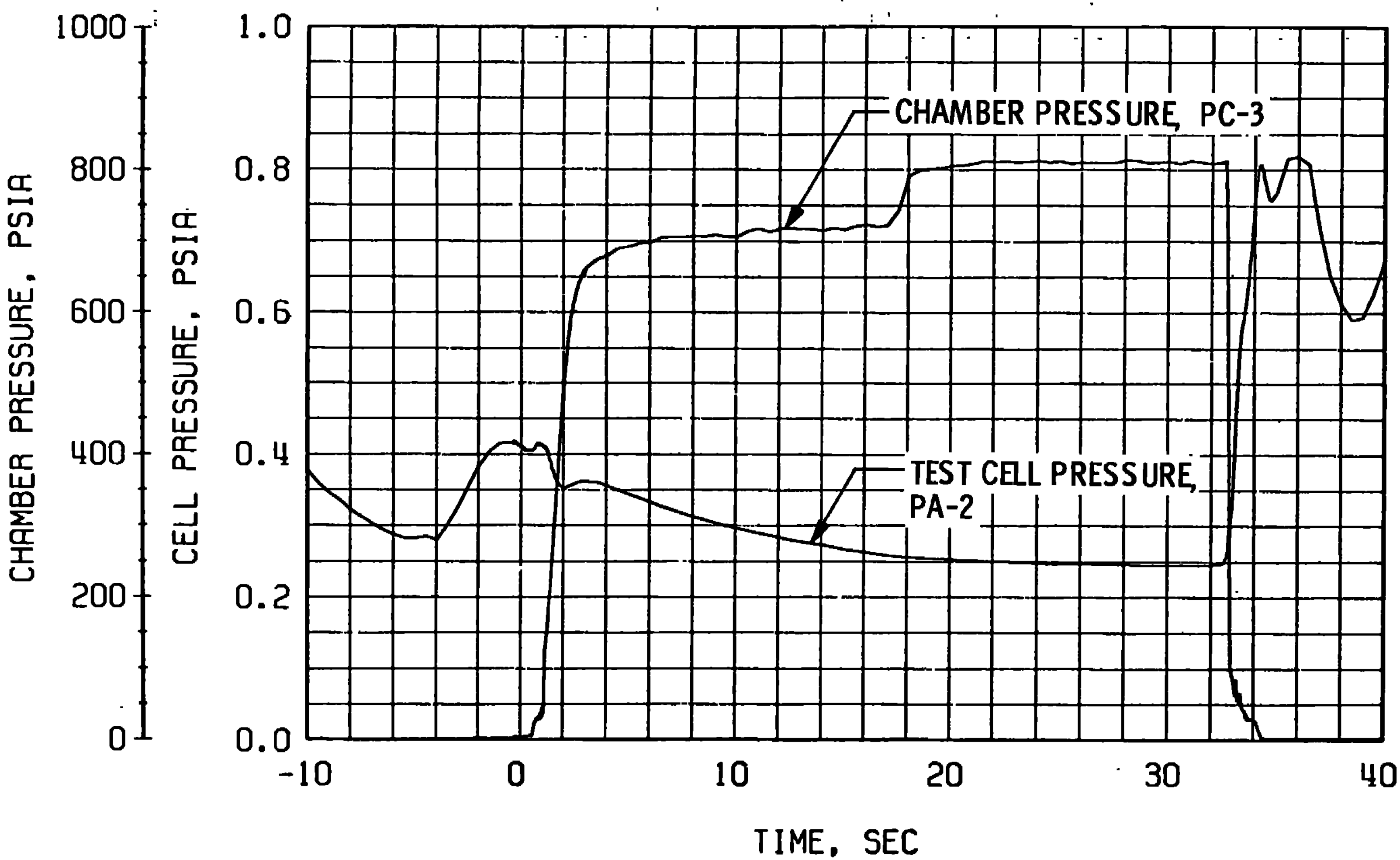


Fig. 54 Engine Ambient and Combustion Chamber Pressures, Firing 27A

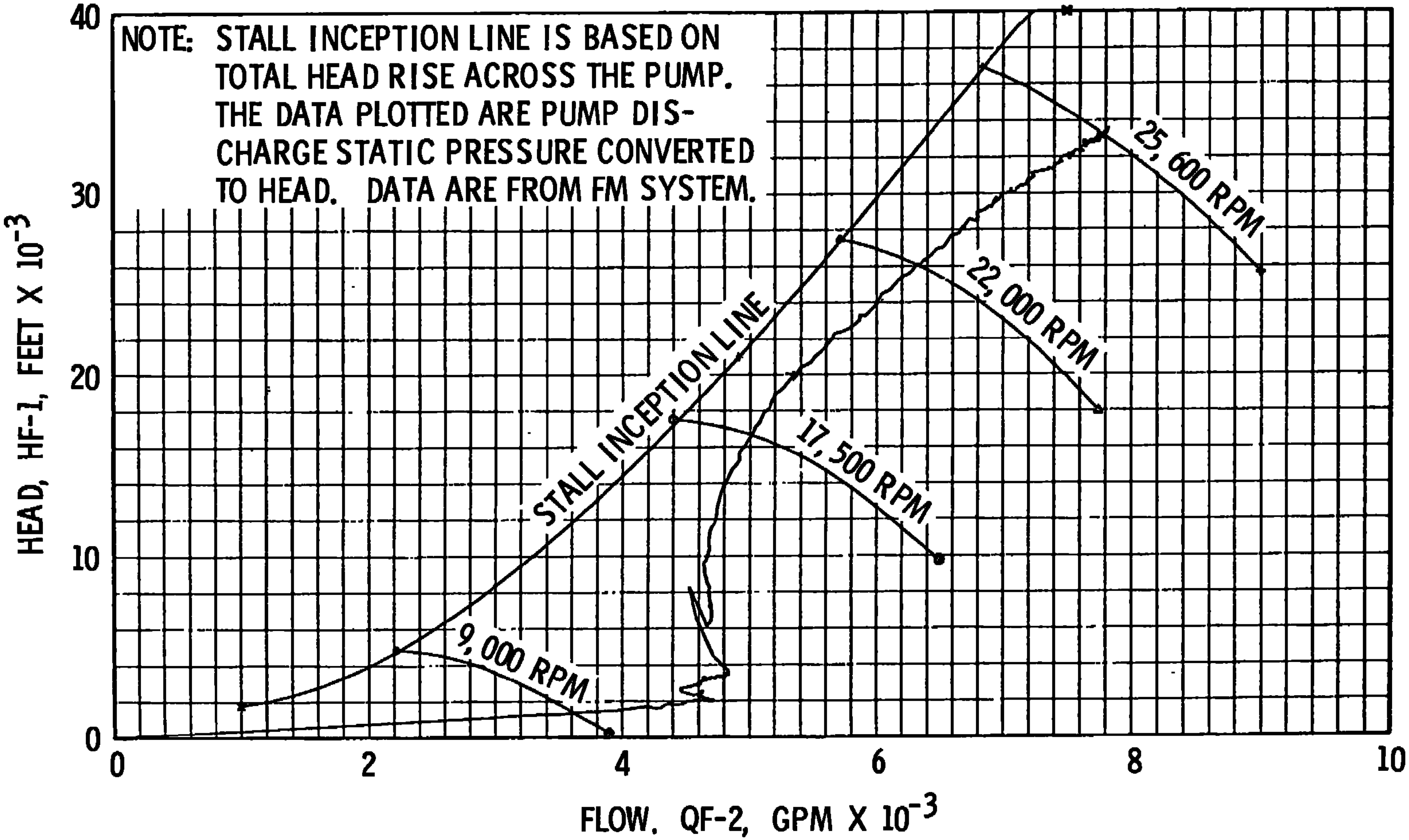


Fig. 55 Fuel Pump Start Transient Performance, Firing 27A

TABLE I
MAJOR ENGINE COMPONENTS

Part Name	P/N	S/N
Thrust Chamber Body	206600-31	4072755
Thrust Chamber Injector Assembly	208021-11	4071421
Fuel Turbopump Assembly	460160-31	4072328
Oxidizer Turbopump Assembly	458175-81	6645876
Start Tank	303439	0038
Augmented Spark Igniter	206280-81	4078806
Gas Generator Fuel Injector and Combustor	308360-11	4088543
Gas Generator Oxidizer Injector and Poppet Assembly	303323	4091740
Helium Regulator Assembly	556948	4072709
Electrical Control Package (Test 24)	502670-11	4078604
Electrical Control Package (Tests 25, 26, and 27)	502670-51	4087776
Primary Flight Instrumentation Package	703685	4077391
Auxiliary Flight Instrumentation Package	703680	4077313
Main Fuel Valve	409120	4062472
Main Oxidizer Valve	411031	4089563
Gas Generator Control Valve	309040	4074190
Start Tank Discharge Valve	306875	4081218
Oxidizer Turbine Bypass Valve (Tests 24 and 25)	409930	4093026
Oxidizer Turbine Bypass Valve (Tests 26 and 27)	409930	4081242
Propellant Utilization Valve	251351-11	4068732
Main-Stage Control Valve	555767	8284307
Ignition Phase Control Valve	555767	8284305
Helium Control Valve	NA5-27273	340919
Start Tank Vent and Relief Valve (Test 24)	557818	4062234
Start Tank Vent and Relief Valve (Tests 25, 26, and 27)	557848	4092989
Helium Tank Vent Valve	NA5-27273	340918
Fuel Bleed Valve	309034	4077233
Oxidizer Bleed Valve	309029	4076750
Augmented Spark Igniter Oxidizer Valve	308880	4089946
Pressure Actuated Shutdown Valve Assembly	557817	4067200
Pressure Actuated Purge Control Valve	557823	4075865
Start Tank Fill/Refill Valve	558000	4072899
Fuel Flowmeter	251225	4076564
Oxidizer Flowmeter	251216	4077137
Fuel Injector Temperature Transducer	NA5-27441	12350
Restartable Ignition Detect Probe		
Tests 24 and 25, Firing 26A	NA5-27298T2	329
Firings 26AA and 26B	NA5-27298T2	329
Firing 27A	NA5-27298T2	102

TABLE II
SUMMARY OF ENGINE ORIFICES

Orifice Name	Part Number	Diameter, in. (Except as Noted)	Date Effective	Comments
Gas Generator Fuel Supply Line	RD251-4107	0.489	December 28, 1967	
Gas Generator Oxidizer Supply Line	RD251-4106	0.296	December 28, 1967	
Oxidizer Turbine Bypass Valve Nozzle	RD273-8002	1.430	November 17, 1967	
Main Oxidizer Valve Closing Control	410437-084	8.42 scfm	January 11, 1968	Thermostatic Orifice
Oxidizer Turbine Exhaust Manifold	RD251-9004	10.000	January 18, 1966	Installed on Engine before Shipment to AEDC
Augmented Spark Igniter Oxidizer Supply Line	406361-3 None	0.125 0.137	January 12, 1968	Gives an Effective Area of 0.110

TABLE III
ENGINE MODIFICATIONS
(BETWEEN TESTS J4-1801-24 AND J4-1801-27)

Modification Number	Completion Date	Description of Modification
RFD[1] - AEDC 62-67	January 11, 1968	Modification of Augmented Spark Igniter Oxidizer Line
RFD - AEDC 69-67	January 11, 1968	Modification of Antiflood Valve Heat Exchanger Inlet Line
RFD 2-68		Retime Main Oxidizer Valve
Test J4-1801-24 1/16/68		
ECP[2] J2-568	January 18, 1968	Modification of Vent and Relief Valve Assembly
ECP J2-492R3	January 18, 1968	Changes to Start Tank Vent and Relief Valve
Test J4-1801-25 1/24/68		
None		
Test J4-1801-26 1/30/68		
RFD 5-68		Addition of Thermocouples to the Oxidizer Turbine Bypass Valve
RFD 6-68		Addition of Thermocouple on Fuel Pump Primary Seal Purge Check Valve
Test J4-1801-27 2/6/68		
None		

[1]RFD-Rocketdyne Field Directive
[2]ECP-Engineering Change Proposal

TABLE IV
ENGINE COMPONENT REPLACEMENTS
(BETWEEN TESTS J4-1801-24 AND J4-1801-27)

Replacement	Completion Date	Component Replaced
UCR[1]-007355	January 11, 1968	Fuel Turbine Shaft Seal
	Test J4-1801-24 1/16/68	
	January 17, 1968	Gas Generator Outlet Temperature Transducer
UCR-007357	January 18, 1968	Start Tank Vent and Relief Valve
UCR-007359	January 22, 1968	Electrical Control Package
	Test J4-1801-25 1/24/68	
UCR-007363	January 25, 1968	Oxidizer Turbine Bypass Valve
	Test J4-1801-26 1/30/68	
UCR-007367	January 30, 1968	Restartable Ignition Detect Probe[2]
UCR-007376	January 30, 1968	Gas Generator Outlet Temperature Probe[2]
UCR-007368		Restartable Ignition Detect Probe
	Test J4-1801-27 2/6/68	
	None	

[1]UCR-Unsatisfactory Condition Report

[2]Changed during Test Period 26

TABLE V
ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE

Time, min: t - 80, t - 70, t - 60, t - 50, t - 40, t - 30, t - 20, t - 10, t - 0, t + 10

Turbopump and Gas Generator Purge (Purge Manifold System)	Helium; 82 - 125 psia 50 - 200°F (Nominal) 6 scfm at Customer Connect	10 min; ← Propellant Drop; 2-min Minimum Following Recirculation; 1 to 3 min
Oxidizer Dome and Gas Generator Liquid Oxygen Injector (Engine Pneumatic System)	Nitrogen; 400 ± 25 psig 50 - 200°F (Minimum) 230 scfm	15 min; 1 sec (Supplied by Engine Helium Tank during Start and Cutoff Transients)
Oxidizer Dome (Facility Line to Port CO3A)	Nitrogen; 400 - 450 psig 100 - 200°F (Nominal) 200 scfm	45 min; On at Engine Cutoff → 10 min
Oxidizer Turbopump Intermediate Seal Cavity (Engine Pneumatic System)	Helium; 400 ± 25 psig Ambient Temperature 2600 - 7000 scfm	15 min; Main-Stage Operation (Supplied by Engine Helium Tank)
Thrust Chamber Jacket (Customer Connect) Panel	Helium; 40 - 60 psig 50 - 200°F (Nominal) 60 scfm	In Addition to → 15 min
	Helium; 12 - 14 psig 50 - 200°F (Nominal) 10 scfm	On at Engine Cutoff; 10 min
Thrust Chamber Temperature Conditioning	Helium; 1000 psig -300°F to Ambient $10 - 20\ lb_m/min$	15 min
Pump Inlet Pressure and Temperature Conditioning	Oxidizer; 35 to 48 psia -298 to -280°F Fuel; 28 to 46 psia -424 to -416°F	
Hydrogen Start Tank and Helium Tank Pressure and Temperature Conditioning	Hydrogen; 1200 to 1400 psia -300 to -140°F Helium; 1700 to 3250 psia -300 to -140°F	46 min
Crossover Duct Temperature Conditioning	Helium; -300°F to Ambient	[1]

[1]Conditioning temperature to be maintained for the last 30 min of pre-fire.

TABLE VI
SUMMARY OF TEST REQUIREMENTS AND RESULTS

Firing Number, J4-1801-		24A		24B	
		Target	Actual	Target	Actual
Time of Day, hr/Firing Date		1220/January 16, 1968		1251/January 16, 1968	
Pressure Altitude at Engine Start, ft (Ref. 1)		100,000	102,000	100,000	108,000
Firing Duration, sec ①		32.500	32.578	7.500	7.588
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	26^{+1}_{-0}	27.1	26^{+1}_{-0}	26.1
	Temperature, °F	-421.4 ± 0.4	-421.7	-421.4 ± 0.4	-421.6
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	45 ± 1.0	45.3	45 ± 1.0	44.8
	Temperature, °F	-295.0 ± 0.4	-295.4	-295.0 ± 0.4	-294.9
Start Tank Conditions at Engine Start	Pressure, psia	1400 ± 10	1397	1300 ± 10	1304
	Temperature, °F	-200 ± 10	-202	-215 ± 10	-204
Helium Tank Conditions at Engine Start	Pressure, psia	---	2667	---	2547
	Temperature, °F	---	-198	---	-190
Thrust Chamber Temperature Conditions at Engine Start/t_0, °F	Throat	-80^{+20}_{-10}	-81	+50 ± 50	+74
	Average	---	-110/-188	---	+31/-215
Crossover Duct Temperature at Engine Start, °F ②	TFTD-2	+50 ± 50	+27	---	+349
	TFTD-3	+50 ± 50	+50	$+170^{+15}_{-10}$	+95
	TFTD-8	+50 ± 50	+25	---	+361
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F		-150 ± 50	-108	-150 ± 50	-102
Fuel Lead Time, sec ①		3.000	2.963	8.000	7.952
Propellant in Engine Time, min		③	90	---	19
Propellant Recirculation Time, min		10	24	10	19
Prevalve Sequencing Logic		Auxiliary	Auxiliary	Normal	Normal
Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F	TOBS-2A	-100 Minimum	+8	-100 Minimum	-23
Start Tank Discharge Valve Body Temperature at Engine Start, °F		+50 ± 25	+32	+50 ± 25	+30
Vibration Safety Count Duration (msec) and Occurrence Time (sec) from t_0 ①		--- / ---	21 / 0.973	--- / ---	4 / 1.011
Gas Generator Outlet Temperature, °F	Initial Peak	---	1516	---	1578
	Second Peak	---	1649	---	1613
Thrust Chamber Ignition (P_c = 100 psia) Time, sec (Ref. t_0) ①		---	0.983	---	1.012
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0) ①		---	0.996	---	1.156
Main-Stage Pressure No. 2, sec (Ref. t_0) ①		---	1.631	---	1.693
550-psia Chamber Pressure Attained, sec (Ref. t_0)		---	1.914	---	2.078
Propellant Utilization Valve Position at Engine Start, Engine Start/t_0 + 10 sec		Null / Closed	Null / Closed	Open / Open	Open / Open

① Data reduced from oscillogram.
② Component conditioning to be maintained within limits for last 15 min before engine start.
③ Propellant in engine time is dependent on main oxidizer valve actuator requirements (minimum of 30 min).

TABLE VI (Continued)

Firing Number, J4-1801-		25A		25B		25C		25D		25E	
		Target	Actual	Target	Actual	Target	Actual	Target	Actual	Target	Actual
Time of Day, hr/Firing Date		1334/January 24, 1968		1405/January 24, 1968		1912/January 24, 1968		1945/January 24, 1968		2054/January 24, 1968	
Pressure Altitude at Engine Start, ft (Ref. 1)		100,000	103,000	100,000	103,000	100,000	107,000	100,000	109,000	100,000	107,000
Firing Duration, sec①		32.5	32.573	7.5	7.587	32.5	32.573	7.5	7.589	1.150	1.131
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	26^{+1}_{-0}	26.8	26^{+1}_{-0}	26.3	26^{+1}_{-0}	28.2	26^{+1}_{-0}	26.2	23.5^{+1}_{-0}	24.4
	Temperature, °F	-421.4 ± 0.4	-421.8	-421.4±0.4	-421.5	-421.4 ± 0.4	-421.8	-421.4±0.4	-421.0	-421.4±0.4	-421.3
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	33^{+1}_{-0}	34.0	45 ± 1	44.7	45 ± 1	45.7	45 ± 1	44.2	28 ± 1	27.7
	Temperature, °F	-294.5 ± 0.4	-294.5	-295.0±0.4	-295.3	-295.0 ± 0.4	-295.3	-295.0 ± 0.4	-294.7	-295.0 ± 0.4	-294.4
Start Tank Conditions at Engine Start	Pressure, psia	1400 ± 10	1385	1300 ± 10	1303	1400 ± 10	1386	1300 ± 10	1300	1400 ± 10	1403
	Temperature, °F	-200 ± 10	-204	-215 ± 10	-216	-200 ± 10	-202	-265 ± 10	-267	-240 ± 10	-240
Helium Tank Conditions at Engine Start	Pressure, psia	---	2555	---	2298	---	2303	---	2116	---	2226
	Temperature, °F	---	-200	---	-215	---	-202	---	-257	---	-235
Thrust Chamber Temperature Conditions at Engine Start/t_0, °F	Throat	-250 ± 25	-266	50 ± 50	+37	-250 ± 25	-236	50 ± 50	+30	-275 ± 25	-262
	Average	---	-289 / -368	---	+22 / -234	---	-280 / -364	---	+35 / -213	---	-281 / -295
Crossover Duct Temperature at Engine Start, °F②	TFTD-2	-100 ± 20	-113	---	357	+50 ± 50	8	---	384	+50 ± 50	-1
	TFTD-3	-100 ± 20	-113	$+170^{+15}_{-0}$	179	+50 ± 50	34	$+170^{+15}_{-0}$	170	+50 ± 50	29
	TFTD-8	-100 ± 20	-107	---	358	+50 ± 50	20	---	357	+50 ± 50	16
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F		-150 ± 50	-143	-150 ± 50	-125	-150 ± 50	-175	-150 ± 50	-173	---	-144
Fuel Lead Time, sec①		3.00	2.969	8.00	7.942	3.00	2.968	8.00	7.935	1.00	1.002
Propellant in Engine Time, min		③	101	---	31	③	174	---	33	30	38
Propellant Recirculation Time, min		10	15	10	25	10	31	10	11	10	18
Prevalve Sequencing Logic		Auxiliary	Auxiliary	Normal	Normal	Auxiliary	Auxiliary	Normal	Normal	Normal	Normal
Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F	TOBS-2A	-100°F Minimum	+5	-100 Minimum	-15	-100 Minimum	+4	-100 Minimum	-18	-100 Minimum	-8
Start Tank Discharge Valve Body Temperature at Engine Start, °F		+50 ± 25	-13	+50 ± 25	-14	+50 ± 25	-64	+50 ± 25	-70	+50 ± 25	+11
Vibration Safety Count Duration, msec and Occurrence Time (sec) from $t_0$①		--- / ---	22 / 1.039	--- / ---	10 / 0.996	--- / ---	15 / 0.995	--- / ---	16 / 0.978	--- / ---	32 / 1.025
Gas Generator Outlet Temperature, °F	Initial Peak	---	1629	---	1535	---	1839	---	1868	---	1388
	Overshoot	---	---	---	1647	---	---	---	1989	---	---
Thrust Chamber Ignition (P_c = 100 psia) Time, sec (Ref. t_0)①		---	1.041	---	0.995	---	0.998	---	0.987	---	1.030
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0)①		---	1.030	---	1.137	---	1.141	---	1.181	---	1.030
Main-Stage Pressure No. 2, sec (Ref. t_0)①		---	1.813	---	1.676	---	1.668	---	1.658	---	---
550-psia Chamber Pressure Attained, sec (Ref. t_0)		---	2.084	---	2.015	---	1.960	---	2.023	---	---
Propellant Utilization Valve Position at Engine Start, deg, Engine Start/t_0 + 10 sec		Null / Closed	Null / Closed	Open / Open	Open / Open	Null / Closed	Null / Closed	Open / Open	Open / Open	Null / Null	Null / Null

①Data reduced from oscillogram.
②Component conditioning to be maintained within limits for last 15 min before engine start.
③Propellant in engine time is dependent on main oxidizer valve actuator requirements (minimum of 30 min).

TABLE VI (Concluded)

Firing Number, J4-1801-26, 27		26A		26AA		26B		27A	
		Target	Actual	Target	Actual	Target	Actual	Target	Actual
Time of Day, hr/Firing Date		0848/ January 30, 1968		0102/ January 31, 1968		0134/ January 31, 1968		1805/ February 6, 1968	
Pressure Altitude at Engine Start, ft (Ref. 1)		100,000	97,000	100,000	91,000	100,000	106,000	100,000	85,000
Firing Duration, sec(1)		32.5	1.137	32.5	32.572	7.5	0.530	32.5	32.575
Fuel Pump Inlet Conditions at Engine Start	Pressure, psia	26.0^{+1}_{-0}	27.4	26.0^{+1}_{-0}	26.1	26.0^{+1}_{-0}	26.4	26.0^{+1}_{-0}	26.8
	Temperature, °F	-421.4 ± 0.4	-422.0	-421.4 ± 0.4	-421.5	-421.4 ± 0.4	-421.7	-421.4 ± 0.4	-421.6
Oxidizer Pump Inlet Conditions at Engine Start	Pressure, psia	33.0^{+1}_{-0}	35.2	33.0^{+1}_{-0}	34.2	45.0 ± 1.0	46.1	33.0^{+1}_{-0}	33.6
	Temperature, °F	-294.5 ± 0.4	-294.5	-294.5 ± 0.4	-294.8	-294.5 ± 0.4	-295.2	-294.5 ± 0.4	-294.5
Start Tank Conditions at Engine Start	Pressure, psia	1250 ± 10	1250	1250 ± 10	1243	1180 ± 10	1178	1250 ± 10	1248
	Temperature, °F	-140 ± 10	-146	-140 ± 10	-141	-210 ± 10	-213	-140 ± 10	-137
Helium Tank Conditions at Engine Start	Pressure, psia	---	2322	---	2214	---	2109	---	2404
	Temperature, °F	---	-141	---	-138	---	-207	---	-134
Thrust Chamber Temperature Conditions at Engine Start, °F	Throat	-200 ± 25	-206	-200 ± 25	-203	+50 ± 50	+40	-250 ± 25	-264
	Average Engine Start / t_0	---	-207 / -376	---	-207 / -372	---	+33 / -220	---	-220 / -281
Crossover Duct Temperature at Engine Start, °F	TFTD-2	-100 ± 20	-105	-100 ± 20	-109	---	343	-100 ± 20	-98
	TFTD-3	-100 ± 20	-152	-100 ± 20	-92	$+170^{+15}_{-0}$	169	-100 ± 20	-45
	TFTD-8	-100 ± 20	-109	-100 ± 20	-99	---	324	-100 ± 20	-86
Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F		-150 ± 50	-120	-150 ± 50	-152	-150 ± 50	-163	-150 ± 50	-152
Fuel Lead Time, sec(1)		8.0 ± 0.1	7.951	8.0 ± 0.1	7.941	8.0 ± 0.1	7.940	3.0 ± 0.1	2.966
Propellant in Engine Time, min		(3)	88	(3)	80	(3)	32	(3)	382
Propellant Recirculation Time, min		10	14	10	10	10	10	10	10
Prevalve Sequencing Logic		Normal	Normal	Normal	Normal	Normal	Normal	Auxiliary	Auxiliary
Bootstrap Line Temperature at Engine Start, °F	TOBS-2A	-100 or Warmer	+17	-100 or Warmer	+17	-100 or Warmer	-18	-100 or Warmer	+17
Start Tank Discharge Valve Body Temperature at Engine Start, °F		---	+26	---	-19	---	-41	---	+21
Vibration Safety Count Duration (msec) and Occurrence Time (sec) from t_0(1)		--- / ---	78 / 1.108	--- / ---	52 / 1.081	--- / ---	--- / ---	--- / ---	20 / 1.077
Gas Generator Outlet Temperature, °F	Initial Peak	---	---	---	1250	---	---	---	1605
	Overshoot	---	---	---	---	---	---	---	---
Main Chamber Ignition (P_c = 100 psia) Time, sec (Ref. t_0)(1)		---	1.110	---	1.113	---	---	---	1.076
Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t_0)(1)		---	1.047	---	1.021	---	---	---	0.012
Main-Stage Pressure No. 2, sec (Ref. t_0)		---	---	---	2.094	---	---	---	1.837
550-psia Chamber Pressure Attained, sec (Ref. t_0)		---	---	---	2.769	---	---	---	2.137
Propellant Utilization Valve Position at Engine Start, deg, Engine Start/t_0 + 10 sec		Open / Closed	Open / ---	Open / Closed	Open / Closed(4)	Open / ---	Open / ---	Null / Closed	Null / Closed(4)

(1) Data reduced from oscillogram.
(2) Component conditioning to be maintained within limits for last 15 min before engine start.
(3) Propellant in engine time is dependent on main oxidizer valve actuator requirements (minimum of 30 min).
(4) The propellant utilization excursion was actually made at t_0 + 25 and t_0 + 17 sec for firings 26AA and 27A, respectively.

TABLE VII
ENGINE VALVE TIMINGS

Firing Number J4-1801-	Start																										
	Start Tank Discharge Valve						Main Fuel Valve			Main Oxidizer Valve First Stage			Main Oxidizer Valve Second Stage			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec
24A	0.00	0.147	0.140	0.448	0.090	0.240	-2.963	0.050	0.064	0.448	0.059	0.055	0.448	0.548	2.149	0.448	0.115	0.030	0.448	0.205	0.075	0.448	0.245	0.293
24B	0.00	0.147	0.136	0.446	0.092	0.237	-7.952	0.055	0.064	0.446	0.060	0.064	0.446	0.712	1.850	0.446	0.120	0.032	0.446	0.205	0.072	0.446	0.228	0.284
25A	0.00	0.165	0.142	0.448	0.092	0.250	-2.969	0.052	0.067	0.448	0.063	0.047	0.448	0.584	1.872	0.448	0.115	0.035	0.448	0.195	0.080	0.448	0.249	0.294
25B	0.00	0.152	0.141	0.449	0.096	0.248	-7.942	0.054	0.056	0.449	0.061	0.059	0.449	0.687	1.875	0.449	0.119	0.028	0.449	0.198	0.090	0.449	0.228	0.285
25C	0.00	0.165	0.151	0.448	0.100	0.260	-2.968	0.054	0.066	0.448	0.060	0.057	0.448	0.694	1.927	0.448	0.120	0.033	0.448	0.200	0.083	0.448	0.240	0.304
25D	0.00	0.160	0.151	0.447	0.101	0.259	-7.935	0.052	0.063	0.447	0.059	0.061	0.447	0.729	1.861	0.447	0.123	0.030	0.447	0.208	0.090	0.447	0.222	0.296
25E	0.00	0.148	0.138	0.450	0.094	0.236	-1.002	0.057	0.060	0.450	0.058	0.057	0.450	0.581	N/A	0.450	0.120	0.036	0.450	0.215	0.092	0.450	---	---
Final Sequence 24	0.00	0.100	0.116	0.447	0.093	0.248	-7.950	0.041	0.069	0.447	0.053	0.045	0.447	0.585	1.735	0.447	0.089	0.036	0.447	0.150	0.068	0.447	0.227	0.288
Final Sequence 25	0.00	0.100	0.112	0.449	0.095	0.250	-1.001	0.043	0.066	0.449	0.055	0.050	0.449	0.593	1.702	0.449	0.086	0.040	0.449	0.154	0.068	0.449	0.225	0.290

TABLE VII (Continued)

Firing Number J4-1801-	Shutdown														
	Main Fuel Valve			Main Oxidizer Valve			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec
24A	32.578	0.130	0.325	32.578	0.083	0.183	32.578	0.053	0.019	32.578	0.025	0.015	32.578	0.229	0.461
24B	7.588	0.125	0.325	7.588	0.080	0.175	7.588	0.060	0.025	7.588	0.035	0.015	7.588	0.209	0.425
25A	32.573	0.140	0.360	32.573	0.088	0.189	32.573	0.058	0.014	32.573	0.029	0.015	32.573	0.243	0.558
25B	7.587	0.120	0.321	7.587	0.081	0.182	7.587	0.061	0.020	7.587	0.037	0.017	7.587	0.218	0.470
25C	32.573	0.137	0.382	32.573	0.088	0.195	32.573	0.066	0.015	32.573	0.030	0.014	32.573	0.231	0.478
25D	7.589	0.121	0.342	7.589	0.083	0.192	7.589	0.070	0.022	7.589	0.035	0.016	7.589	0.216	0.467
25E	1.131	0.113	0.304	1.131	0.020	0.054	1.131	0.082	0.029	1.131	0.046	0.025	1.131	---	---
Final Sequence 24	7.168	0.084	0.243	7.168	0.065	0.135	7.168	0.079	0.027	7.168	0.050	0.022	7.168	0.212	0.508
Final Sequence 25	5.802	0.087	0.238	5.802	0.064	0.133	5.802	0.085	0.025	5.802	0.058	0.022	5.802	0.216	0.538

Notes:
1. All valve signal times are referenced to t_0.
2. Valve delay time is the time required for initial valve movement after the valve "open" or valve "closed" solenoid has been energized.
3. Final sequence check is conducted without propellants and within 12 hr before testing.
4. Data reduced from oscillogram.

TABLE VII (Concluded)

Firing Number J4-1801-1	Start																				
	Start Tank Discharge Valve						Main Fuel Valve			Main Oxidizer Valve First Stage			Main Oxidizer Valve Second Stage			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec
26A	0	0.143	0.131	0.449	0.090	0.240	-7.951	0.053	0.062	0.449	0.057	0.054	0.449	0.598	---	0.449	0.113	0.030	0.449	0.184	0.070	0.449	0.226	0.329
26AA	0	0.148	0.138	0.449	0.095	0.249	-7.941	0.058	0.065	0.449	0.057	0.056	0.449	0.613	1.820	0.449	0.111	0.033	0.449	0.190	0.073	0.449	0.253	0.312
26B	0	0.148	0.137	----	---	---	-7.940	0.055	0.062	---	---	---	---	---	---	---	----	---	---	---	---	---	---	---
27A	0	0.142	0.133	0.450	0.092	0.238	-2.966	0.059	0.062	0.450	0.064	0.051	0.450	0.562	1.906	0.450	0.114	0.030	0.450	0.189	0.078	0.450	0.244	0.308
Final Sequence 26	0	0.099	0.110	0.449	0.096	0.241	-1.001	0.046	0.064	0.449	0.050	0.049	0.449	0.577	1.738	0.449	0.087	0.027	0.449	0.149	0.067	0.449	0.212	0.301
Final Sequence 27	0	0.099	0.109	0.449	0.095	0.240	-1.000	0.045	0.067	0.449	0.056	0.043	0.449	0.588	1.740	0.449	0.084	0.039	0.449	0.151	0.066	0.449	0.224	0.293

Firing Number J4-1801-	Shutdown														
	Main Fuel Valve			Main Oxidizer Valve			Gas Generator Fuel Poppet			Gas Generator Oxidizer Poppet			Oxidizer Turbine Bypass Valve		
	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec
26A	1.137	0.115	0.317	1.137	---	---	1.137	0.074	0.022	1.137	0.041	0.019	1.137	0.130	0.583
26AA	32.572	0.137	0.372	32.572	0.089	0.193	32.572	0.061	0.030	32.572	0.029	0.017	32.572	0.269	0.534
26B	0.530	0.091	0.288	---	---	---	---	---	---	---	---	---	---	---	---
27A	32.575	0.143	0.381	32.575	0.085	0.199	32.575	0.063	0.025	32.575	0.029	0.015	32.575	0.292	0.488
Final Sequence 26	---	0.085	0.235	---	0.051	0.134	---	0.076	0.028	---	0.052	0.018	---	0.209	0.540
Final Sequence 27	---	0.083	0.238	---	0.068	0.127	---	0.074	0.030	---	0.051	0.023	---	0.219	0.554

Notes:
1. All valve signal times are referenced to t_0.
2. Valve delay time is the time required for initial valve movement after the valve "open" or valve "closed" solenoid has been energized.
3. Final sequence check is conducted without propellants and within 12 hr before testing.
4. Data reduced from oscillogram.

TABLE VIII
ENGINE PERFORMANCE SUMMARY

Firing Number J4-1801-		24A Site	24A Normalized	25A Site	25A Normalized	25C Site	25C Normalized	26AA Site	26AA Normalized	27A Site	27A Normalized
Overall Engine Performance	Thrust, lb_f	236,463	233,901	237,050	234,741	236,470	234,568	236,056	233,747	237,774	235,306
	Chamber Pressure, psia	792	780	794	783	792	782	790	779	796	784
	Mixture Ratio	5.72	5.70	5.46	5.44	5.49	5.47	5.63	5.63	5.47	5.46
	Fuel Weight Flow, lb_m/sec	81	80	85	84	84	84	85	84	85	84
	Oxidizer Weight Flow, lb_m/sec	464	457	463	456	464	458	460	454	465	459
	Total Weight Flow, lb_m/sec	545	537	548	540	548	541	545	538	551	542
Thrust Chamber Performance	Mixture Ratio	5.95	5.93	5.66	5.65	5.70	5.68	5.63	5.63	5.67	5.67
	Total Weight Flow, lb_m/sec	538	530	541	533	541	534	538	531	543	535
	Characteristic Velocity, ft/sec	8057	8060	8030	8032	8011	8016	8037	8036	8016	8017
Fuel Turbopump Performance	Pump Efficiency, percent	74	74	74	74	74	74	74	74	74	74
	Pump Speed, rpm	27,380	27,141	27,366	27,160	27,308	27,094	27,243	27,040	27,384	27,113
	Turbine Efficiency, percent	60	60	64	64	63	63	62	62	63	63
	Turbine Pressure Ratio	7.2	7.2	7.1	7.1	7.1	7.1	7.3	7.3	7.2	7.2
	Turbine Inlet Temperature, °F	1231	1207	1220	1198	1219	1196	1213	1194	1236	1213
	Turbine Weight Flow, lb_m/sec	7.1	7.0	7.0	6.9	7.0	7.0	7.0	7.0	7.1	7.0
Oxidizer Turbopump Performance	Pump Efficiency, percent	80	80	80	80	80	80	80	80	81	80
	Pump Speed, rpm	8638	8573	8657	8590	8660	8597	8617	8550	8679	8604
	Turbine Efficiency, percent	48	48	50	50	50	49	50	50	49	49
	Turbine Pressure Ratio	2.7	2.7	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
	Turbine Inlet Temperature, °F	799	781	786	771	791	774	746	733	802	785
	Turbine Weight Flow, lb_m/sec	6.3	6.2	6.2	6.1	6.2	6.2	6.2	6.2	6.3	6.2
Gas Generator Performance	Mixture Ratio	0.96	0.94	0.95	0.94	0.95	0.94	0.95	0.94	0.96	0.95
	Chamber Pressure, psia	686	677	678	670	680	673	683	675	690	682

Notes:
1. Site data are calculated from test data.
2. Normalized data are corrected to standard pump inlet and engine ambient pressure conditions.
3. Input data are test data averaged from 29 to 30 sec.
4. Site and normalized data were computed using the Rocketdyne PAST 640 modification zero computer program.

APPENDIX III
INSTRUMENTATION

The instrumentation for AEDC tests J4-1801-24 through 27 is tabulated in Table III-1. The location of selected major engine instrumentation is shown in Fig. III-1. The same instrumentation applies for all four tests, except for that added for test 27, which is noted by an asterisk.

TABLE III-1
INSTRUMENTATION LIST

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Current		amp					
ICC	Control		0 to 30	x		x		
IIC	Ignition		0 to 20	x		x		
	Event							
EECL	Engine Cutoff Lockin		On/Off	x		x		
EECO	Engine Cutoff Signal		On/Off	x	x	x		
EES	Engine Start Command		On/Off	x		x		
EFBVC	Fuel Bleed Valve Closed Limit		Open/Closed	x				
EFPVC/O	Fuel Prevalve Closed/Open Limit		Closed/Open	x		x		
EHCS	Helium Control Solenoid		On/Off	x		x		
EID	Ignition Detected		On/Off	x		x		
EIPCS	Ignition Phase Control Solenoid		On/Off	x		x		
EMCS	Main-Stage Control Solenoid		On/Off	x		x		
EMP-1	Main-Stage Pressure No. 1		On/Off	x		x		
EMP-2	Main-Stage Pressure No. 2		On/Off	x		x		
EOBVC	Oxidizer Bleed Valve Closed Limit		Open/Closed	x				
EOPVC	Oxidizer Prevalve Closed Limit		Closed	x		x		
EOPVO	Oxidizer Prevalve Open Limit		Open	x		x		
ESTDCS	Start Tank Discharge Control Solenoid		On/Off	x	x	x		
RASIS-1	Augmented Spark Igniter Spark No. 1		On/Off			x		
RASIS-2	Augmented Spark Igniter Spark No. 2		On/Off			x		
RGGS-1	Gas Generator Spark No. 1		On/Off			x		
RGGS-2	Gas Generator Spark No. 2		On/Off			x		
	Flows		gpm					
QF-1A	Fuel	PFF	0 to 9000	x		x		
QF-2	Fuel	PFFA	0 to 9000	x	x	x		
QFRP	Fuel Recirculation		0 to 160	x				
QO-1A	Oxidizer	POF	0 to 3000	x		x		
QO-2	Oxidizer	POFA	0 to 3000	x	x	x		
QORP	Oxidizer Recirculation		0 to 50	x			x	
	Heat Flux		$\frac{\text{watts}}{\text{steradians-cm}^2}$					
RTCEP	Radiation Thrust Chamber Exhaust Plume		0 to 7	x				
	Position		Percent Open					
LFVT	Main Fuel Valve		0 to 100	x		x		
LGGVT	Gas Generator Valve		0 to 100	x		x		
LOTBVT	Oxidizer Turbine Bypass Valve		0 to 100	x		x		
LOVT	Main Oxidizer Valve		0 to 100	x	x	x		
LPUTOP	Propellant Utilization Valve		0 to 100	x		x	x	
LSTDVT	Start Tank Discharge Valve		0 to 100	x		x		
	Pressure		psia					
PA1	Test Cell		0 to 0.5	x		x		
PA2	Test Cell		0 to 1.0	x	x			

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Pressure		psia					
PA3	Test Cell		0 to 5.0	x			x	
PC-1P	Thrust Chamber	CG1	0 to 1000	x			x	
PC-3	Thrust Chamber	CG1A	0 to 1000	x	x	x		
PCGG-1P	Gas Generator Chamber Pressure		0 to 1000	x	x	x		
PCGG-2	Gas Generator Chamber	GG1A	0 to 1000	x				
PFASIJ	Augmented Spark Igniter Fuel Injection		0 to 1000	x				
PFJ-1A	Main Fuel Injection	CF2	0 to 1000	x		x		
PFJ-2	Main Fuel Injection	CF2A	0 to 1000	x	x			
PFJGG-1A	Gas Generator Fuel Injection	GF4	0 to 1000	x				
PFJGG-2	Gas Generator Fuel Injection	GF4	0 to 1000	x		x		
PFMI	Fuel Jacket Inlet Manifold	CF1	0 to 2000	x				
PFPC-1A	Fuel Pump Balance Piston Cavity	PF5	0 to 1000	x				
PFPD-1P	Fuel Pump Discharge	PF3	0 to 1500	x				
PFPD-2	Fuel Pump Discharge	PF2	0 to 1500	x	x	x		
PFPI-1	Fuel Pump Inlet		0 to 100	x				x
PFPI-2	Fuel Pump Inlet		0 to 200	x				x
PFPI-3	Fuel Pump Inlet		0 to 200		x	x		
PFPPSD-1	Fuel Pump Primary Seal Drain		0 to 200	x				
PFPPSD-2*	Fuel Pump Primary Seal Drain		0 to 100	x				
PFPS-1P	Fuel Pump Interstage	PF6	0 to 200	x				
PFRPO	Fuel Recirculation Pump Outlet		0 to 60	x				
PFRPR	Fuel Recirculation Pump Return		0 to 50	x				
PFST-1P	Fuel Start Tank	TF1	0 to 1500	x		x		
PFST-2	Fuel Start Tank	TF1	0 to 1500	x				x
PFTSP-1	Fuel Turbine Seal Purge Line		0 to 100	x				
PFUT	Fuel Tank Ullage		0 to 100	x				
PFVI	Fuel Tank Pressurization Line Nozzle Inlet		0 to 1000	x				
PFVL	Fuel Tank Pressurization Line Nozzle Throat		0 to 1000	x				
PGGOC	Gas Generator Opening Control		0 to 500	x				
PGGVB *	Gas Generator Valve Body		0 to 50	x				
PHECMO	Pneumatic Control Module Outlet		0 to 750	x				
PHEOP	Oxidizer Recirculation Pump Purge		0 to 150	x				
PHES	Helium Supply		0 to 5000	x				
PHET-1P	Helium Tank	NN1	0 to 3500	x		x		
PHET-2	Helium Tank	NN1	0 to 3500	x				x
PHRO-1A	Helium Regulator Outlet	NN2	0 to 750	x	x			
POBSC	Oxidizer Bootstrap Conditioning		0 to 50	x				
POBV	Gas Generator Oxidizer Bleed Valve	GO2	0 to 2000	x		x		
POJ-1A	Main Oxidizer Injection	CO3	0 to 1000	x		x		
POJ-2	Main Oxidizer Injection	CO3A	0 to 1000	x		x		

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Pressure		psia					
POJGG-1A	Gas Generator Oxidizer Injection	GO5	0 to 1000	x		x		
POJGG-2	Gas Generator Oxidizer Injection	GO5	0 to 1000	x				
POPBC-1A	Oxidizer Pump Bearing Coolant	PO7	0 to 500	x				
POPD-1P	Oxidizer Pump Discharge	PO3	0 to 1500	x				
POPD-2	Oxidizer Pump Discharge	PO2	0 to 1500	x	x	x		
POPI-1	Oxidizer Pump Inlet		0 to 100	x				x
POPI-2	Oxidizer Pump Inlet		0 to 200	x				x
POPI-3	Oxidizer Pump Inlet		0 to 100			x		
POPSC-1A	Oxidizer Pump Primary Seal Cavity	PO6	0 to 50	x				
PORPO	Oxidizer Recirculation Pump Outlet		0 to 1[illegible]5	x				
PORPR	Oxidizer Recirculation Pump Return		0 to 100	x				
POTI-1A	Oxidizer Turbine Inlet	TG3	0 to 200	x				
POTO-1A	Oxidizer Turbine Outlet	TG4	0 to 100	x				
POUT	Oxidizer Tank Ullage		0 to 100	x				
POVCC	Main Oxidizer Valve Closing Control		0 to 500	x	x			
POVI	Oxidizer Tank Pressurization Line Nozzle Inlet		0 to 1000	x				
POVL	Oxidizer Tank Pressurization Line Nozzle Throat		0 to 1000	x				
PPUVI-1A	Propellant Utilization Valve Inlet	PO8	0 to 1000	x				
PPUVO-1A	Propellant Utilization Valve Outlet	PO9	0 to 500	x				
PTCFJP	Thrust Chamber Fuel Jacket Purge		0 to 100	x				
PTCP	Thrust Chamber Purge		0 to 15	x				
PTPP	Turbopump and Gas Generator Purge		0 to 250	x				
	Speeds		rpm					
NFP-1P	Fuel Pump	PFV	0 to 30,000	x	x	x		
NFRP	Fuel Recirculation Pump		0 to 15,000	x				
NOP-1P	Oxidizer Pump	POV	0 to 12,000	x	x	x		
NORP	Oxidizer Recirculation Pump		0 to 15,000	x				
	Temperatures		°F					
TA1	Test Cell (North)		-50 to +800	x				
TA2	Test Cell (East)		-50 to -800	x				
TA3	Test Cell (South)		-50 to +800	x				
TA4	Test Cell (West)		-50 to -800	x				
TAIP-1A	Auxiliary Instrument Package		-300 to +200	x				
TBPM	Bypass Manifold		-325 to -200	x				
TBSC	Oxidizer Bootstrap Conditioning		-350 to +150	x				
TECP-1P	Electrical Controls Package	NST1A	-300 to +200	x			x	
TFASIJ	Augmented Spark Igniter Fuel Injection	IFT1	-425 to +100	x		x		

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TFASIL-1	Augmented Spark Igniter Line		-300 to +200	x				
TFASIL-2	Augmented Spark Igniter Line		-300 to +300	x				
TFBV-1A	Fuel Bleed Valve	GFT1	-425 to -375	x				
TFD-1	Fire Detection		0 to 1000	x			x	
TFJ-1P	Main Fuel Injection	CFT2	-425 to -250	x	x	x		
TFPD-1P	Fuel Pump Discharge	PFT1	-425 to -400	x	x	x		
TFPD-2	Fuel Pump Discharge	PFT1	-425 to -400	x				
TFPDD	Fuel Pump Discharge Duct		-320 to -300	x				
TFPI-1	Fuel Pump Inlet		-425 to -400	x				x
TFPI-2	Fuel Pump Inlet		-425 to -400	x				x
TFPPSD-1*	Fuel Pump Primary Seal Drain		-425 to +100	x				
TFPSP-1*	Fuel Pump Seal Purge		-425 to +100	x				
TFRPO	Fuel Recirculation Pump Outlet		-425 to -410	x				
TFRPR	Fuel Recirculation Pump Return Line		-425 to -250	x				
TFRT-1	Fuel Tank		-425 to -410	x				
TFRT-3	Fuel Tank		-425 to -410	x				
TFST-1P	Fuel Start Tank	TFT1	-350 to +100	x				
TFST-2	Fuel Start Tank	TFT1	-350 to +100	x				x
TFTD-1	Fuel Turbine Discharge Duct		-200 to +800	x				
TFTD-2	Fuel Turbine Discharge Duct		-200 to 1000	x			x	
TFTD-3	Fuel Turbine Discharge Duct		-200 to +1000	x			x	
TFTD-3R	Fuel Turbine Discharge Line		-200 to +900	x				
TFTD-4	Fuel Turbine Discharge Duct		-200 to +1000	x				
TFTD-5	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-6	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-7	Fuel Turbine Discharge Duct		-200 to +1400	x				
TFTD-8	Fuel Turbine Discharge Duct		-200 to +1400	x			x	
TFTI-1P	Fuel Turbine Inlet	TFT1	0 to 1800	x			x	
TFTO	Fuel Turbine Outlet	TFT2	0 to 1800	x				
TFTSD-1	Fuel Turbine Seal Drain Line		-300 to +100	x				
TGGO-1A	Gas Generator Outlet	GGT1	0 to 1800	x		x		
TGGVRS	Gas Generator Valve Retaining Screw		-100 to +100	x				
THET-1P	Helium Tank	NNT1	-350 to +100	x				x
TNODP	LO_2 Dome Purge		0 to -300	x				
TOBS-1	Oxidizer Bootstrap Line		-300 to -250	x				
TOBS-2	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2A	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-2B	Oxidizer Bootstrap Line		-300 to +250	x				
TOBS-3	Oxidizer Bootstrap Line		-300 to -250	x				
TOBS-4	Oxidizer Bootstrap Line		-300 to +250	x				
TOBV-1A	Oxidizer Bleed Valve	GOT2	-300 to -250	x				
TOPB-1A	Oxidizer Pump Bearing Coolant	POT4	-300 to -250	x				

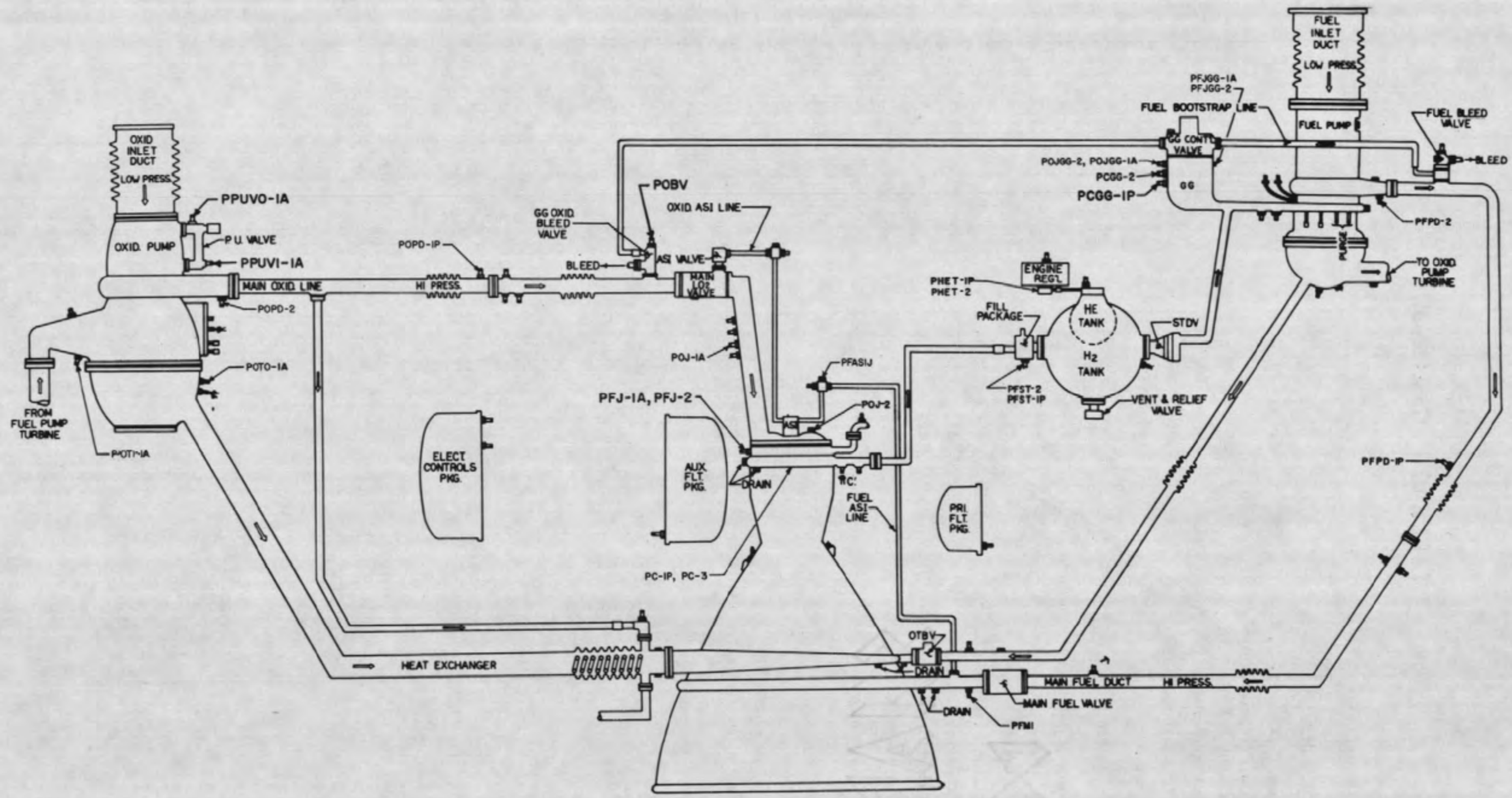
TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No	Range	Micro-SADIC	Magnetic Tape	Oscillo-graph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TOPD-1P	Oxidizer Pump Discharge	POT3	-300 to -250	x	x	x	x	
TOPD-2	Oxidizer Pump Discharge	POT3	-300 to -250	x				
TOPI-1	Oxidizer Pump Inlet		-310 to -270	x				x
TOPI-2	Oxidizer Pump Inlet		-310 to -270	x				x
TORPO	Oxidizer Recirculation Pump Outlet		-300 to -250	x				
TORPR	Oxidizer Recirculation Pump Return		-300 to -140	x				
TORT-1	Oxidizer Tank		-300 to -287	x				
TORT-1B	Oxidizer Tank		-300 to -287	x				
TORT-3	Oxidizer Tank		-300 to -287	x				
TOTBV-1*	Oxidizer Turbine Bypass Valve		-100 to +300	x				
TOTBV-2*	Oxidizer Turbine Bypass Valve		-100 to +300	x				
TOTI-1F	Oxidizer Turbine Inlet	TGT3	0 to 1200	x			x	
TOTO-1P	Oxidizer Turbine Outlet	TGT4	0 to 1000	x				
TOVL	Oxidizer Tank Pressurization Line Nozzle		-300 to +100	x				
TPCC	Pre-Chill Controller		-425 to -300	x				
TPIP-1P	Primary Instrument Package		-300 to +200	x				
TSC2-1	Thrust Chamber Skin		-300 to +500	x				
TSC2-2	Thrust Chamber Skin		-300 to +500	x				
TSC2-3	Thrust Chamber Skin		-300 to +500	x				
TSC2-4	Thrust Chamber Skin		-300 to +500	x				
TSC2-5	Thrust Chamber Skin		-300 to +500	x				
TSC2-6	Thrust Chamber Skin		-300 to +500	x				
TSC2-7	Thrust Chamber Skin		-300 to +500	x				
TSC2-8	Thrust Chamber Skin		-300 to +500	x				
TSC2-9	Thrust Chamber Skin		-300 to +500	x				
TSC2-10	Thrust Chamber Skin		-300 to +500	x				
TSC2-11	Thrust Chamber Skin		-300 to +500	x				
TSC2-12	Thrust Chamber Skin		-300 to +500	x				
TSC2-13	Thrust Chamber Skin		-300 to +500	x			x	
TSC2-14	Thrust Chamber Skin		-300 to +500	x				
TSC2-15	Thrust Chamber Skin		-300 to +500	x				
TSC2-16	Thrust Chamber Skin		-300 to +500	x				
TSC2-17	Thrust Chamber Skin		-300 to +500	x				
TSC2-18	Thrust Chamber Skin		-300 to +500	x				
TSC2-19	Thrust Chamber Skin		-300 to +500	x				
TSC2-20	Thrust Chamber Skin		-300 to +500	x				
TSC2-21	Thrust Chamber Skin		-300 to +500	x				
TSC2-22	Thrust Chamber Skin		-300 to +500	x				
TSC2-23	Thrust Chamber Skin		-300 to +500	x				
TSC2-24	Thrust Chamber Skin		-300 to +500	x				
TSOVAL-1	Oxidizer Valve Closing Control Line		-200 to +100	x				
TSOVC-1	Oxidizer Valve Actuator Cap		-325 to +150	x				

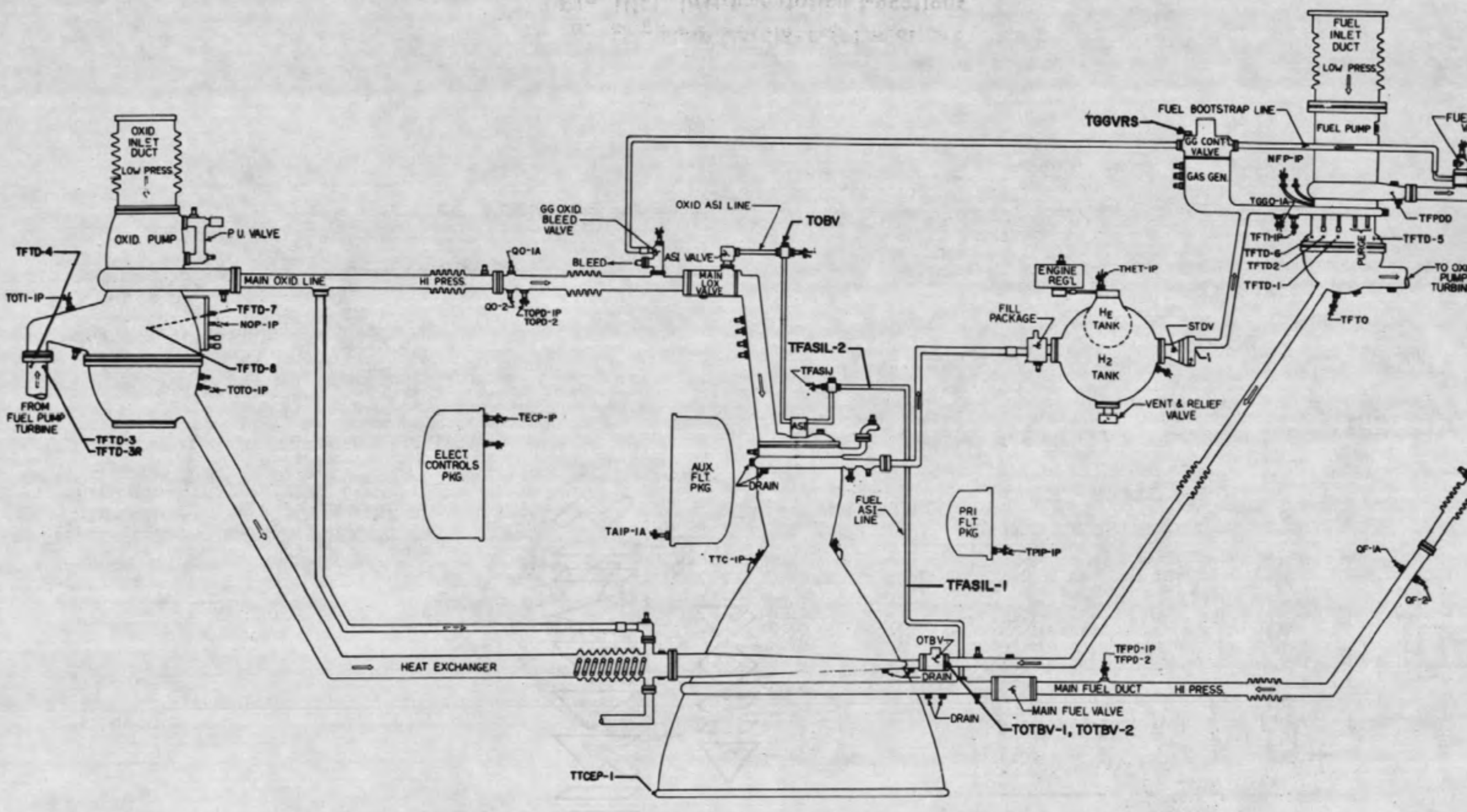
TABLE III-1 (Concluded)

AEDC Code	Parameter	Tap No.	Range	Micro-SADIC	Magnetic Tape	Oscillograph	Strip Chart	X-Y Plotter
	Temperatures		°F					
TSTC	Start Tank Conditioning		-350 to +150	x				
TSTDVOC	Start Tank Discharge Valve Opening Control Port		-350 to +100	x			x	
TTC-1P	Thrust Chamber Jacket (Control)	CS1	-425 to +500	x			x	
TTCEP-1	Thrust Chamber Exit		-425 to +500	x				
TTPP	Turbopump Purge		-150 to +150	x				
	Vibrations		g's					
UFPR	Fuel Pump Radial 90 deg		±200		x			
UOPR	Oxidizer Pump Radial 90 deg		±200		x			
UTCD-1	Thrust Chamber Dome		±500		x	x		
UTCD-2	Thrust Chamber Dome		±500		x	x		
UTCD-3	Thrust Chamber Dome		±500		x	x		
U1VSC	No. 1 Vibration Safety Counts		On/Off			x		
U2VSC	No. 2 Vibration Safety Counts		On/Off					
	Voltage		volts					
VCB	Control Bus		0 to 36	x		x		
VIB	Ignition Bus		0 to 36	x		x		
VIDA	Ignition Detect Amplifier		9 to 16	x		x		
VPUTEP	Propellant Utilization Valve Excitation		0 to 5	x				

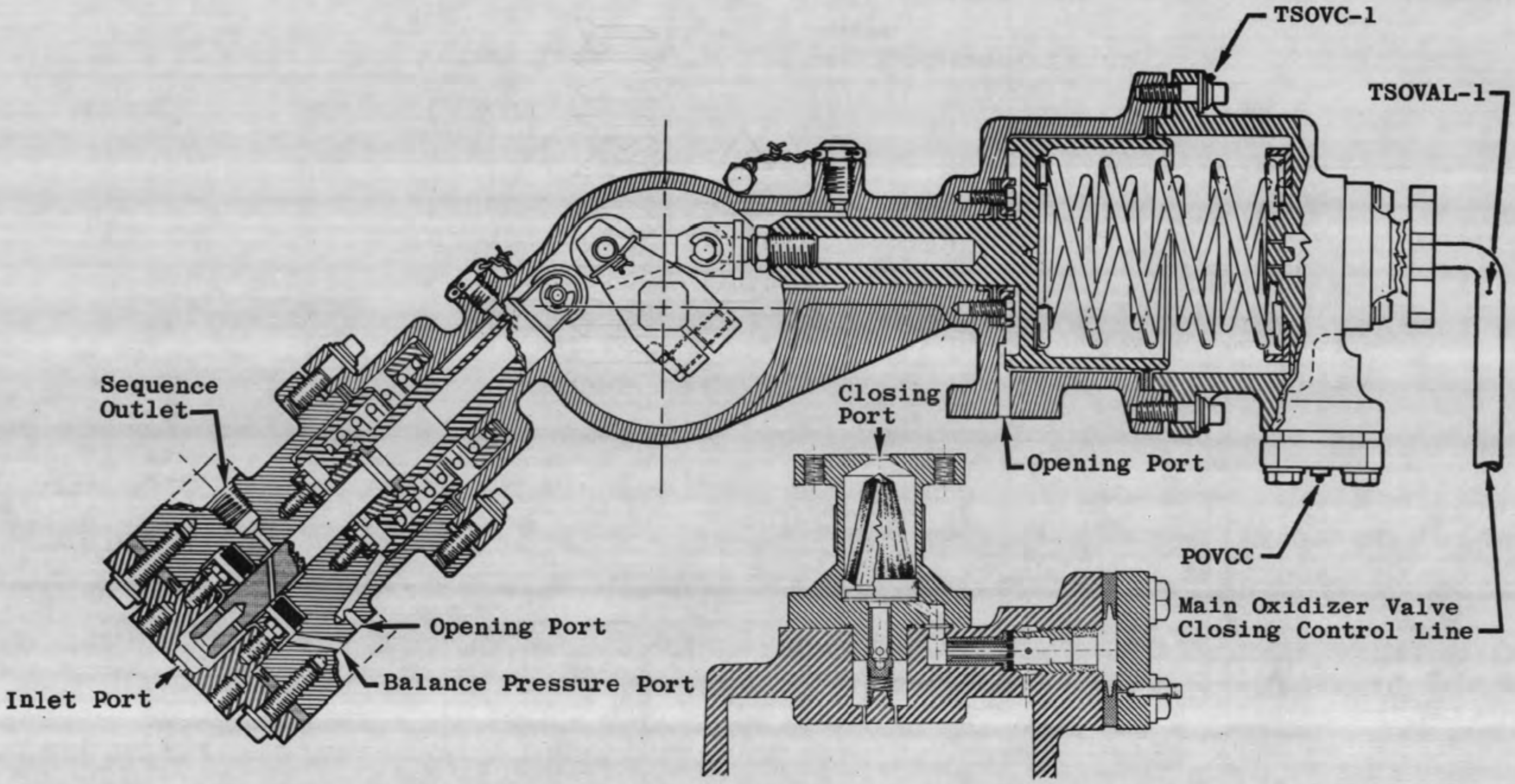
*Applies to test 27 only.



a. Engine Pressure Tap Locations
Fig. III-1 Instrumentation Locations

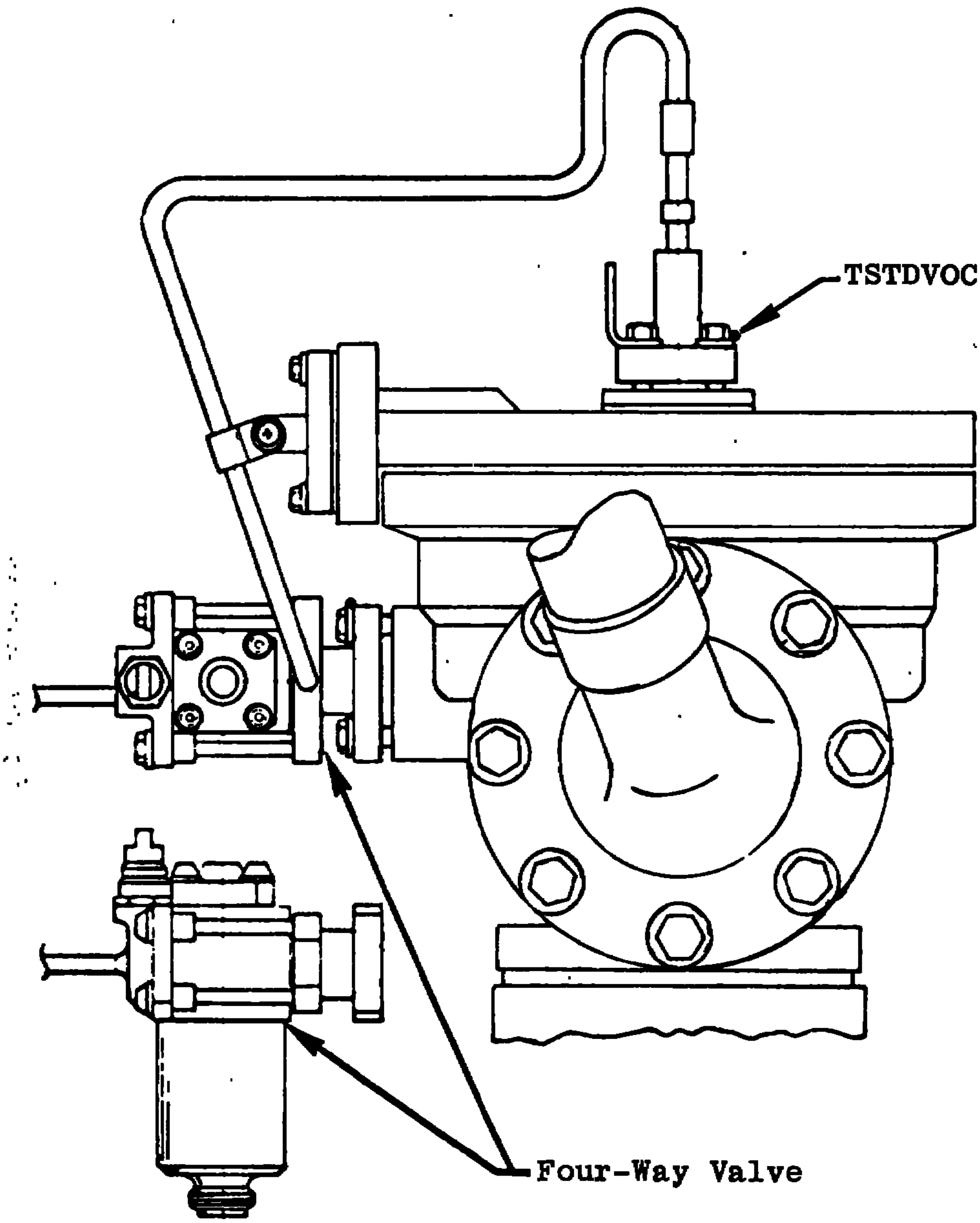


b. Engine Temperature, Flow, and Speed Instrumentation Locations
Fig. III-1 Continued

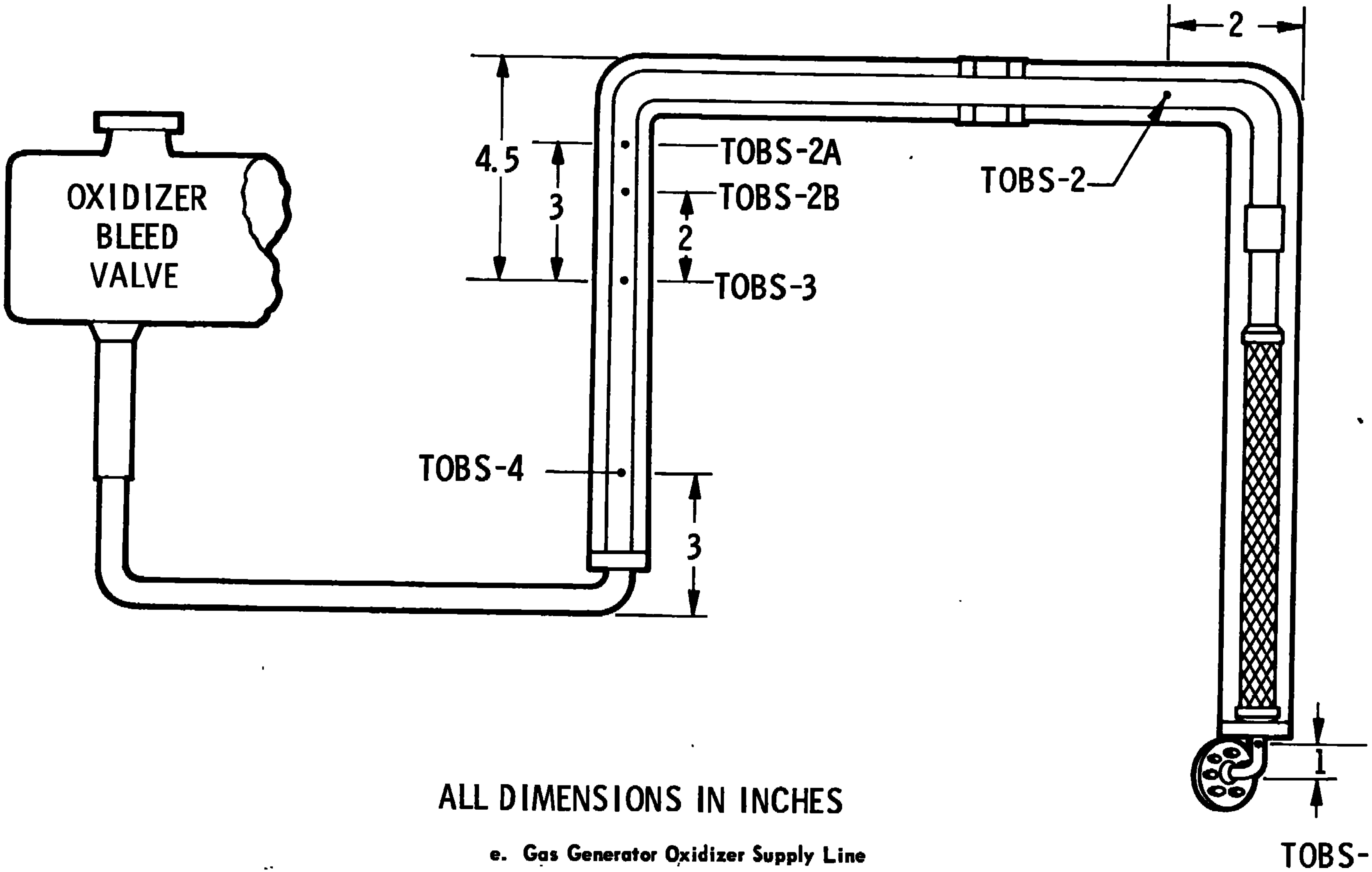


c. Main Oxidizer Valve

Fig. III-1 Continued



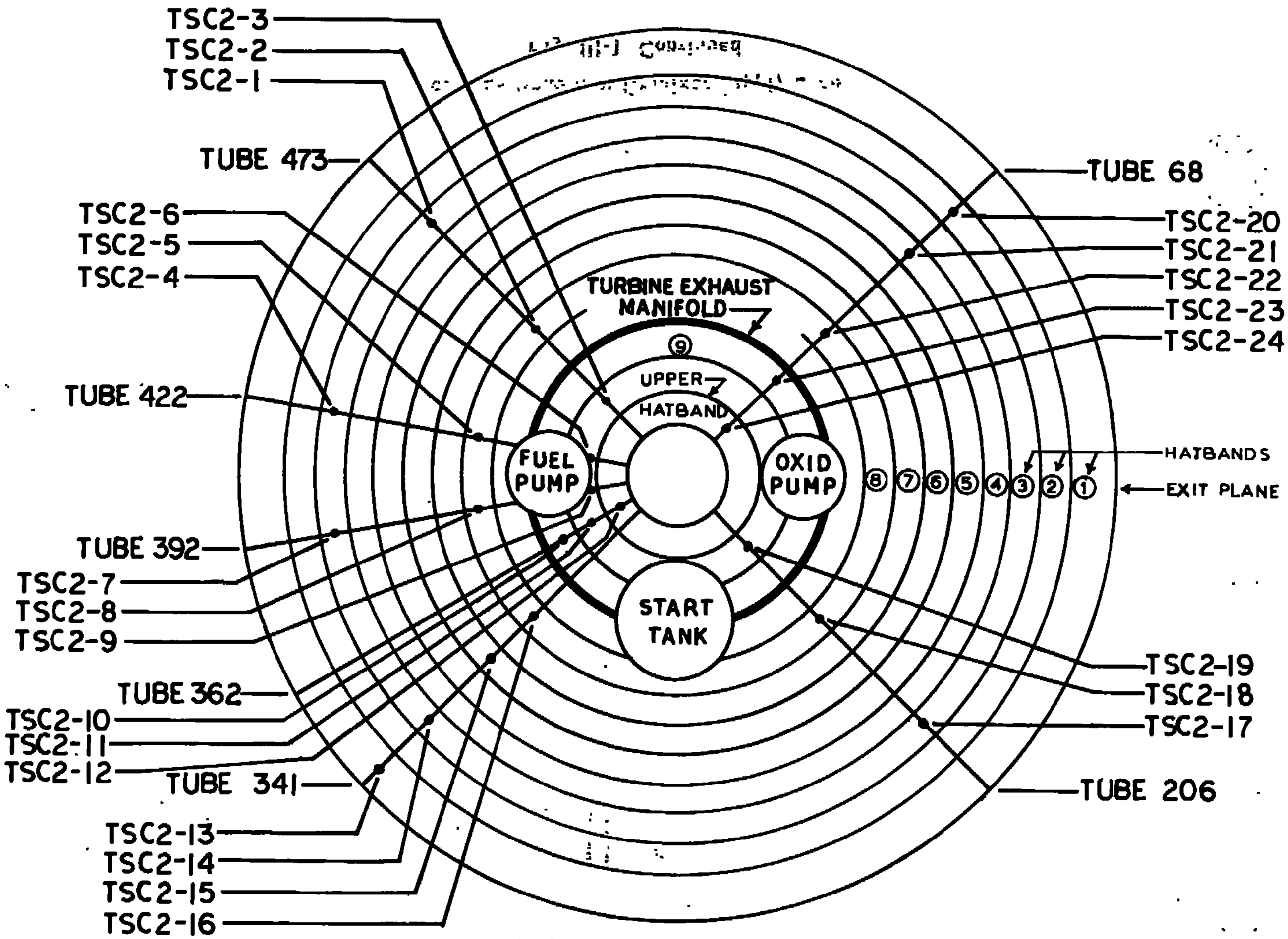
d. Start Tank Discharge Valve
Fig. III-1 Continued



ALL DIMENSIONS IN INCHES

e. Gas Generator Oxidizer Supply Line

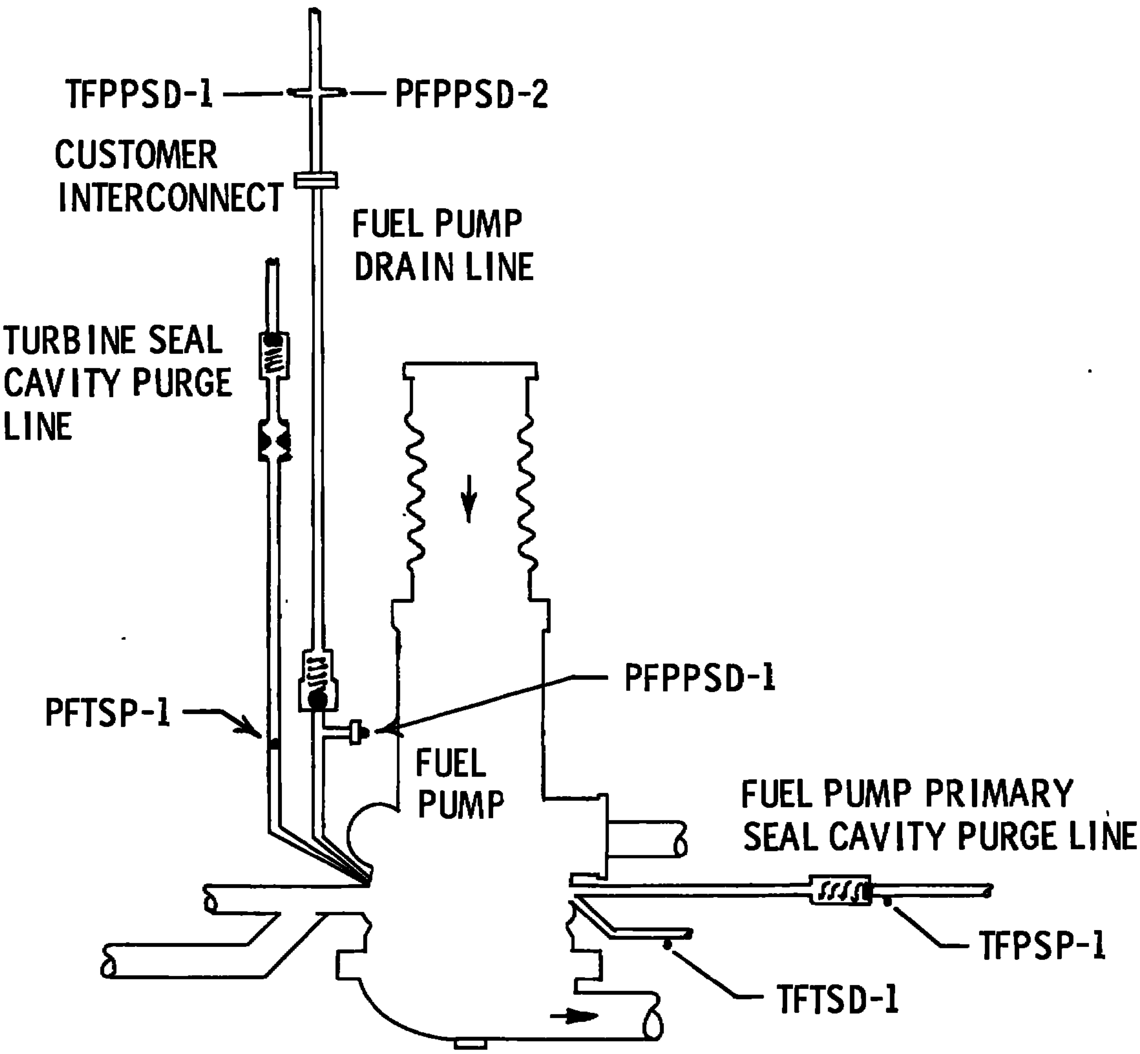
Fig. III-1 Continued



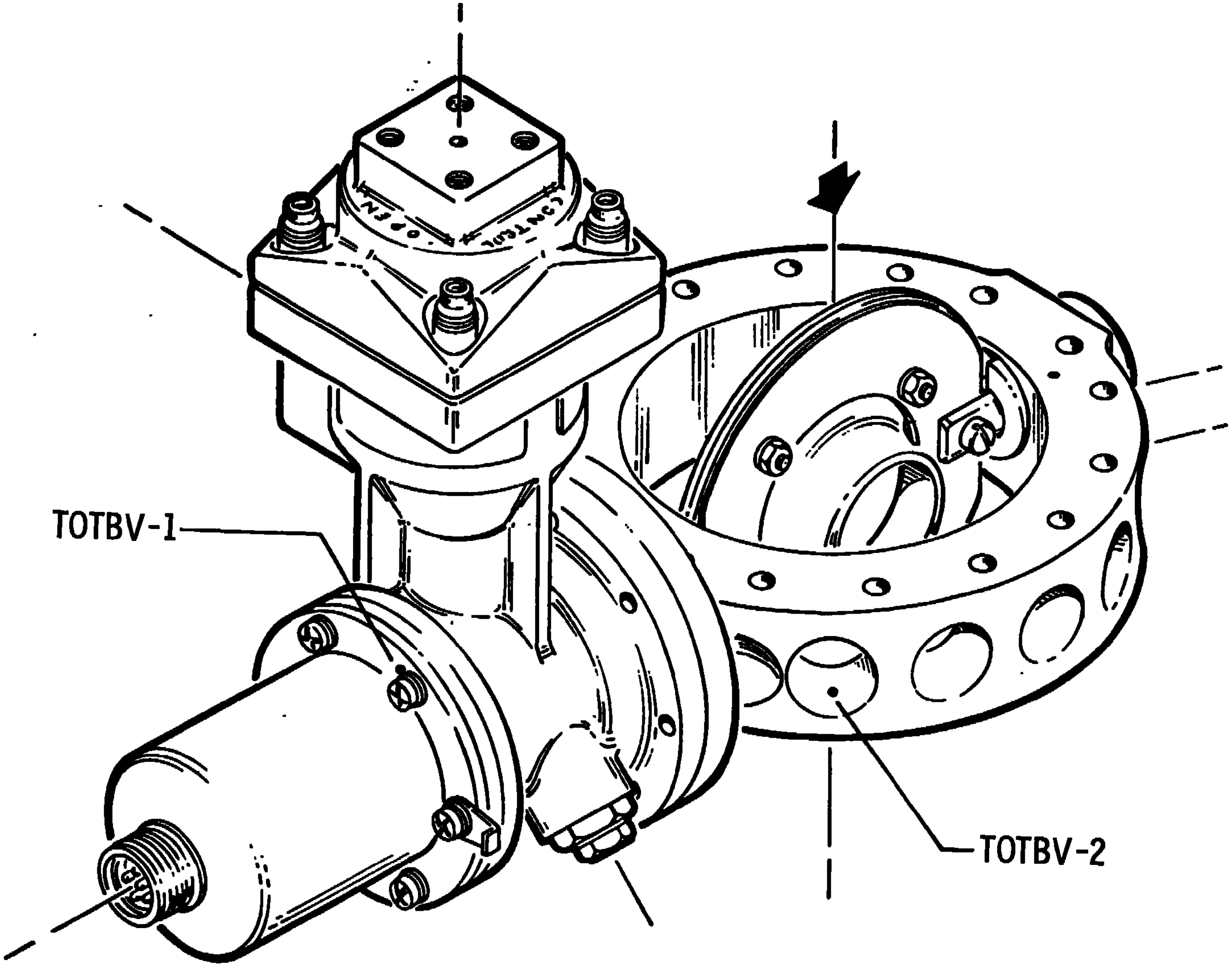
VIEW LOOKING AFT

f. Thrust Chamber

Fig. III-1 Continued



g. Fuel Pump and Turbine Purge and Drain Line
Fig. III-1 Continued



h. Oxidizer Turbine Bypass Valve
Fig. III-1 Concluded

APPENDIX IV
METHODS OF CALCULATIONS (PERFORMANCE PROGRAM)

TABLE IV-1
PERFORMANCE PROGRAM DATA INPUTS

Item No.	Parameter
1	Thrust Chamber (Injector Face) Pressure, psia
2	Thrust Chamber Fuel and Oxidizer Injection Pressures, psia
3	Thrust Chamber Fuel Injection Temperature, °F
4	Fuel and Oxidizer Flowmeter Speeds, Hz
5	Fuel and Oxidizer Engine Inlet Pressures, psia
6	Fuel and Oxidizer Pump Discharge Pressures, psia
7	Fuel and Oxidizer Engine Inlet Temperatures, °F
8	Fuel and Oxidizer (Main Valves) Temperatures, °F
9	Propellant Utilization Valve Center Tap Voltage, volts
10	Propellant Utilization Valve Position, volts
11	Fuel and Oxidizer Pump Speeds, rpm
12	Gas Generator Chamber Pressure, psia
13	Gas Generator (Bootstrap Line at Bleed Valve) Temperature, °F
14	Fuel* and Oxidizer Turbine Inlet Pressure, psia
15	Oxidizer Turbine Discharge Pressure, psia
16	Fuel and Oxidizer Turbine Inlet Temperature, °F
17	Oxidizer Turbine Discharge Temperature, °F

*At AEDC, fuel turbine inlet pressure is calculated from gas generator chamber pressure.

NOMENCLATURE

A	Area, in.^{2}
B	Horsepower, hp
C*	Characteristic velocity, ft/sec
C_p	Specific heat at constant pressure, Btu/lb/°F
D	Diameter, in.
H	Head, ft
h	Enthalpy, Btu/lb_m
M	Molecular weight
N	Speed, rpm
P	Pressure, psia
Q	Flow rate, gpm
R	Resistance, sec^2/ft^3-in.^{2}
r	Mixture ratio
T	Temperature, °F
TC*	Theoretical characteristic velocity, ft/sec
W	Weight flow, lb/sec
Z	Pressure drop, psi
β	Ratio
γ	Ratio of specific heats
η	Efficiency
θ	Degrees
ρ	Density, lb/ft^3

SUBSCRIPTS

A	Ambient
AA	Ambient at thrust chamber exit
B	Bypass nozzle

BIR	Bypass nozzle inlet (Rankine)
BNI	Bypass nozzle inlet (total)
C	Thrust chamber
CF	Thrust chamber, fuel
CO	Thrust chamber, oxidizer
CV	Thrust chamber, vacuum
E	Engine
EF	Engine fuel
EM	Engine measured
EO	Engine oxidizer
EV	Engine, vacuum
e	Exit
em	Exit measured
F	Thrust
FIT	Fuel turbine inlet
FM	Fuel measured
FY	Thrust, vacuum
f	Fuel
G	Gas generator
GF	Gas generator fuel
GO	Gas generator oxidizer
H1	Hot gas duct No. 1
H1R	Hot gas duct No. 1 (Rankine)
H2R	Hot gas duct No. 2 (Rankine)
IF	Inlet fuel
IO	Inlet oxidizer
ITF	Isentropic turbine fuel
ITO	Isentropic turbine oxidizer
N	Nozzle
NB	Bypass nozzle (throat)

NV	Nozzle, vacuum
O	Oxidizer
OC	Oxidizer pump calculated
OF	Outlet fuel pump
OFIS	Outlet fuel pump isentropic
OM	Oxidizer measured
OO	Oxidizer outlet
PF	Pump fuel
PO	Pump oxidizer
PUVO	Propellant utilization valve oxidizer
RNC	Ratio bypass nozzle, critical
SC	Specific, thrust chamber
SCV	Specific thrust chamber, vacuum
SE	Specific, engine
SEV	Specific, engine vacuum
T	Total
T_O	Turbine oxidizer
TEF	Turbine exit fuel
TEFS	Turbine exit fuel (static)
TF	Fuel turbine
TIF	Turbine inlet fuel (total)
TIFM	Turbine inlet, fuel, measured
TIFS	Turbine inlet fuel isentropic
TIO	Turbine inlet oxidizer
t	Throat
V	Vacuum
v	Valve
XF	Fuel tank repressurant
XO	Oxidizer tank repressurant

PERFORMANCE PROGRAM EQUATIONS

MIXTURE RATIO

Engine

$$r_E = \frac{W_{EO}}{W_{EF}}$$

$$W_{EO} = W_{OM} - W_{XO}$$

$$W_{EF} = W_{FM} - W_{XF}$$

$$W_E = W_{EO} + W_{EF}$$

Thrust Chamber

$$r_C = \frac{W_{CO}}{W_{CF}}$$

$$W_{CO} = W_{OM} - W_{XO} - W_{GO}$$

$$W_{CF} = W_{FM} - W_{XF} - W_{GF}$$

$$W_{XO} = 0.9 \text{ lb/sec for 230K Engine}$$

$$W_{XF} = 2.1 \text{ lb/sec for 230K Engine}$$

$$W_{GO} = W_T - W_{GF}$$

$$W_{GF} = \frac{W_T}{1 + r_G}$$

$$W_T = \frac{P_{TIF}\, A_{TIF}\, K_7}{TC^*_{TIF}}$$

$$K_7 = 32.174$$

$$W_C = W_{CO} + W_{CF}$$

CHARACTERISTIC VELOCITY

Thrust Chamber

$$C^* = \frac{K_7\, P_c\, A_t}{W_C}$$

$$K_7 = 32.174$$

DEVELOPED PUMP HEAD

Flows are normalized by using the following inlet pressures, temperatures, and densities.

$$P_{IO} = 39 \text{ psia}$$

$$P_{IF} = 30 \text{ psia}$$

$$\rho_{IO} = 70.79 \text{ lb/ft}^3$$

$$\rho_{IF} = 4.40 \text{ lb/ft}^3$$

$$T_{IO} = -295.212\,°F$$

$$T_{IF} = -422.547\,°F$$

Oxidizer

$$H_O = K_4 \left(\frac{P_{OO}}{\rho_{OO}} - \frac{P_{IO}}{\rho_{IO}}\right)$$

$$K_4 = 144$$

$$\rho = \text{National Bureau of Standards Values f (P,T)}$$

Fuel

$$H_f = 778.16\,\Delta h_{OFIS}$$

$$\Delta h_{OFIS} = h_{OFIS} - h_{IF}$$

$$h_{OFIS} = f(P,T)$$

$$h_{IF} = f(P,T)$$

PUMP EFFICIENCIES

Fuel, Isentropic

$$\eta_f = \frac{h_{OFIS} - h_{IF}}{h_{OF} - h_{IF}}$$

$$h_{OF} = f(P_{OF}, T_{OF})$$

Oxidizer, Isentropic

$$\eta_O = \eta_{OC}\, Y_O$$

$$\eta_{OC} = K_{4O} \left(\frac{Q_{PO}}{N_O}\right)^2 + K_{5O} \left(\frac{Q_{PO}}{N_O}\right) + K_{6O}$$

$$K_{4O} = 5.0526$$

$$K_{5O} = 3.8611$$

$$K_{6O} = 0.0733$$

$$Y_O = 1.000$$

TURBINES

Oxidizer, Efficiency

$$\eta_{TO} = \frac{B_{TO}}{B_{ITO}}$$

$$B_{TO} = K_5 \frac{W_{PO} H_O}{\eta_O}$$

$$K_5 = 0.001818$$

$$W_{PO} = W_{OM} + W_{PUVO}$$

$$W_{PUVO} = \sqrt{\frac{Z_{PUVO} \rho_{OO}}{R_v}}$$

$$Z_{PUVO} = A + B (P_{OO})$$

$$A = -1597$$

$$B = 2.3818$$

IF $P_{OO} \geq 1010$ Set $P_{OO} = 1010$

$$\ln Rv \Big| = A_3 + B_3 (\theta_{PUVO}) + C (\theta_{PUVO})^3 + D_3 (e)^{\frac{\theta_{PUVO}}{7}} + E_3 (\theta_{PUVO}) (e)^{\frac{\theta_{PUVO}}{7}} + F_3 \left[(e)^{\frac{\theta_{PUVO}}{7}}\right]^2$$

$$A_3 = 5.5659 \times 10^{-1}$$

$$B_3 = 1.4997 \times 10^{-2}$$

$$C_3 = 7.9413 \times 10^{-6}$$

$$D_3 = 1.2343$$

$$E_3 = -7.2554 \times 10^{-2}$$

$$F_3 = 5.0691 \times 10^{-2}$$

$$\theta_{PUVO} = 16.5239$$

Fuel, Efficiency

$$\eta_{TF} = \frac{B_{TF}}{B_{ITF}}$$

$$B_{ITF} = K_{10} \, \Delta h_f \, W_T$$

$$\Delta h_f = h_{TIF} - h_{TEF}$$

$$B_{TF} = B_{PF} = K_5 \left(\frac{W_{PF} H_f}{\eta_f}\right)$$

$$W_{PF} = W_{FM}$$

$$K_{10} = 1.4148$$

$$K_5 = 0.001818$$

Oxidizer, Developed Horsepower

$$B_{TO} = B_{PO} + K_{56}$$

$$B_{PO} = K_5 \frac{W_{PO} H_O}{\eta_O}$$

$$K_{56} = -15$$

Fuel, Developed Horsepower

$$B_{TF} = B_{PF}$$

$$B_{PF} = K_5 \frac{W_{PF} H_f}{\eta_f}$$

$$W_{PF} = W_{FM}$$

Fuel, Weight Flow

$$W_{TF} = W_T$$

Oxidizer Weight Flow

$$W_{TO} = W_T - W_B$$

$$W_B = \left[\frac{2K_7\ \gamma_{H2}}{\gamma_{H2-1}} (P_{RNC})^{\frac{2}{\gamma_{H2}}}\right]^{½} \left[1 - (P_{RNC})^{\frac{\gamma_{H2-1}}{\gamma_{H2}}}\right] \frac{A_{NB}\ P_{BNI}}{(R_{H2} T_{BIR})^{½}}$$

$$P_{RNC} = f\ (\beta_{NB}, \gamma_{H2})$$

$$\beta_{NB} = \frac{D_{NB}}{D_B}$$

$$\gamma_{H2}, M_{H2} = f(T_{H2R}, r_G)$$

$$A_{NB} = K_{13}\ D_{NB}$$

$$K_{13} = 0.7854$$

$$T_{BIR} = T_{TIO} + 460$$

$$P_{BNI} = P_{TEFS}$$

$$P_{TEFS} = \text{Iteration of } P_{TEF}$$

$$P_{TEF} = P_{TEFS}\left[1 + K_8 \left(\frac{W_T}{P_{TEFS}}\right)^2 \frac{T_{H2R}}{D^4{}_{TEF}\ M_{H2}} \left(\frac{\gamma_{H2-1}}{\gamma_{H2}}\right)\right]^{\frac{\gamma_{H2}}{\gamma_{H2-1}}}$$

$$K_8 = 38.8983$$

GAS GENERATOR

Mixture Ratio

$$r_G = D_1 (T_{H1})^3 + C_1 (T_{H1})^2 + B_1 (T_{H1}) + A_1$$

$$A_1 = 0.2575$$

$$B_1 = 5.586 \times 10^{-4}$$

$$C_1 = -5.332 \times 10^{-9}$$

$$D_1 = 1.1312 \times 10^{-11}$$

$$T_{H1} = T_{TIFM}$$

Flows

$$TC^*_{TIF} = D_2 (T_{H1})^3 + C_2 (T_{H1})^2 + B_2 (T_{H1}) + A_2$$

$$A_2 = 4.4226 \times 10^3$$

$$B_2 = 3.2267$$

$$C_2 = -1.3790 \times 10^{-3}$$

$$D_2 = 2.6212 \times 10^{-7}$$

$$P_{TIF} = P_{TIFS} \left[1 + K_8 \left(\frac{W_T}{P_{TIFS}} \right)^2 \frac{T_{HIR}}{D^4_{TIF} M_{H1}} \frac{\gamma_{H1} - 1}{\gamma_{H1}} \right]^{\frac{\gamma_{H1}}{\gamma_{H1} - 1}}$$

$$K_8 = 38.8983$$

Note: P_{TIF} is determined by iteration.

$$T_{HIR} = T_{TIF}$$

$$M_{H1}, \gamma_{H1}, C_p, r_{H1} = f\,(T_{HIR}, r_G)$$

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*
Arnold Engineering Development Center
ARO, Inc., Operating Contractor
Arnold Air Force Station, Tennessee

2a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

2b. GROUP
N/A

3. REPORT TITLE
ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TESTS J4-1801-24 THROUGH 27)

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
January 16, 24, 30, and February 6, 1968

5. AUTHOR(S) *(First name, middle initial, last name)*
D. E. Franklin and H. J. Counts, Jr., ARO, Inc.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
June 1968	155	5

8a. CONTRACT OR GRANT NO. AF40(600)-1200

b. PROJECT NO. 9194

c. System 921E

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
AEDC-TR-68-91

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
N/A

10. DISTRIBUTION STATEMENT Subject to special export controls; transmittal to foreign governments or foreign nationals requires approval of NASA, Marshall Space Flight Center (I-E-J), Huntsville, Alabama. Transmittal outside of DOD requires approval of NASA, Marshall Space Flight Center (I-E-J),

11. SUPPLEMENTARY NOTES Huntsville, Alabama.
Available in DDC.

12. SPONSORING MILITARY ACTIVITY
NASA, Marshall Space Flight Center (I-E-J), Huntsville, Alabama

13. ABSTRACT

Eleven firings of the Rocketdyne J-2 rocket engine were conducted during test periods J4-1801-24 through 27 on January 16, 24, and 30 and February 6, 1968, in Test Cell J-4 of the Large Rocket Facility. The firings were accomplished at pressure altitudes ranging from 85,000 to 109,000 ft at engine start to investigate (1) engine start transients for both S-IVB first burn and (2) 80-min orbital restart with the engine in a 230,000-lb_f-thrust configuration. Engine components were thermally conditioned to temperatures representative of an S-IVB first burn or 80-min orbital restart. The total accumulated firing duration for the four test periods was 188.43 sec. Engine operation appeared to be satisfactory.

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DD FORM 1 NOV 65 1473

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Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
J-2 rocket engines						
altitude testing						
engine start						
orbital restart						